ANNOTATED BIBLIOGRAPHY

Many of the following documents were collected by the Task Force. Other's arrived later and continue to arrive. A few late-arriving documents have not yet been abstracted. The collection activity will continue under the long-term Impact Assessment.

[AEDC 1995]

DoD Integrated Test and Evaluation Successes Using Computing Resources. Arnold Engineering Development Center. October 1995.

This paper outlines AEDC's role in providing knowledge for risk management and decision making during the development and operation of the system. Using an Integrated Test and Evaluation (IT&E) approach to systems support development, AEDC combines analysis tools with concurrent ground tests of multiple subsystems to accelerate and improve the integration of the subsystems before flight. Twenty-one successes using IT&E in the general fields of aerodynamics, turbine engines, customer support, and future opportunities are presented with estimated cost savings for selected systems.

[Allen et al. 1994]

G. Allen and R. D. Smith "TACSIM: Intelligence Training for Tomorrow's Battlefield". *Military Intelligence*. Ft. Hauchuca, AZ, October-December 1994, Vol. 20 (4) 23-27.

This article provides information on Tactical Simulation (TACSIM), an interactive computer-based simulation to support intelligence training. TACSIM originally was developed as the "Post Oak" simulator in 1979 and renamed to TACSIM in 1980. Its initial function exercised intelligence missions utilizing scripted scenario databases against enemy forces and generating reports in US Message Text Format (USMTF). According to the article, TACSIM development continues and currently supports the Distributed Interactive Simulation (DIS) and Aggregate Level Simulation Protocol (ALSP). This is a thorough article covering TACSIM from its origin in 1979 to the present. It contains detail on TACSIM's employment and lists collection assets, but remains understandable to those outside the intelligence community. When discussing scripting, sensor flexibility, and TACSIM analysis, the article focuses on the function and responsibilities of military intelligence. This contributor (TACSIM) to ALSP is an integral part in the overall success of the Confederation of Models currently incorporated in ALSP. Here is a pertinent article that portrays this simulation in an easily understood manner.

[Angier et al. 1993]
B. N. Angier, E. A. Alluisi, and S. A. Horowitz. *Simulators and Enhanced Training*. IDA Paper P-2672. Institute for Defense Analyses, Alexandria, VA, 1992.

This study focused on the issue of whether increased use of individual and networked simulators and training devices held potential to maintain military manpower capability during a period of declining budgets and force levels. It reviewed findings of several previous studies, highlighting key findings. The operating costs of flight simulators are about 10% of actual equipment per hour trained; if acquisition cost is taken into account, the yearly operating cost is about 33% of actual equipment. The majority of tasks trained on simulators (59%) have significant positive transfer to flight performance (transfer effectiveness ratios greater than 0.33). The authors suggested a cautious approach to increased use of simulation in lieu of flying hours, but felt that it would not be overly risky to transfer perhaps 5% of the flying hour budget to simulator acquisition and operation. Analysis of an effectiveness comparison between SIMNET and home-station field training indicates that SIMNET is extremely effective in increasing performance for SIMNET-trainable tasks relative to field training. Tradeoff analyses showed that investment in SIMNET-like facilities could be repaid by a 8-14% decrease in OPTEMPO.

[Acquisition Task Force on M&S 1994]
"Report on Proceeding: Cost & Operational Effectiveness Analysis Focus Group. Utility of Synthetic Environments in Support of Operational Test and Evaluation 1993.

This report outlines the final results of the focus group convened by the Acquisition Task Force on Modeling and Simulation (ATFM&S) to address the uses of M&S in COEAs. The participants were asked to look beyond the confines of the COEA process for ways that COEA products and by-products could be used in non-traditional products

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[Armed Forces Journal. 1993]
"Training & Simulation: Battleground for Digitized Warriors." *Armed Forces Journal International*. Washington, DC, November 1993, Vol. 132 (4) 40-41.

This article focuses on the missions of the Army's Simulation, Training, and Instrumentation Command (STRICOM), headquartered in Orlando, FL. STRICOM is responsible for technical management of Department of Defense efforts in Distributed Interactive Simulation, networking simulation components throughout the world, and developing and purchasing specialized training and simulation devices. It describes STRICOM's efforts in linking battle labs and battlefields, and concludes with a brief discussion of its progress in modeling equipment for allies. This short article, which provides the reader with a basic knowledge of STRICOM, educates those previously unaware of this command and highlights its importance to DoD's efforts to link training and testing resources throughout the services.

[Army Science Board 1989]
Close Combat (Heavy) Training Strategy for the 1990s. Army Science Board, Washington, DC. March 1989.

The ASB conducted a study of the training strategy for the heavy forces, with a focus on the role that simulation might have in future Army training. The board expressed the opinion that it would be possible to reduce OPTEMPO and training ammunition by 15-20% while maintaining the same or a better level of unit performance provided that: (1) compensating funds would be provided to enhance and operate simulators, (2) simulators could be tailored to the special needs of units, and (3) simulators were used effectively. The reduction assumed a base-level main gun tank annual ammunition allocation of 100 rounds (active) and 48 rounds (NG), 800 miles per vehicle and 15.8 flight hours per pilot per month.

[Automotive Industry Action Group 1994]
Solid Modeling White Paper. Automotive Industry Action Group (AIAG). Southfield, MI, June 1994.

This white paper is the result of a request from the AIAG OEM CAD/CAM task force that a work group composed of members from Chrysler, Ford, and General Motors be formed to write a white paper on solid modeling. Representatives from each of the three automobile manufacturers provide information concerning their past and present experience with solid modeling, as well as indications of their strategies for the future. Phone: (810) 358-3570.

[*Automotive Engineering* 1994]
“Driving Simulation at Ford.” *Automotive Engineering.* September 1994, 37-40.

This article reviews Ford’s experience in using simulation in studying driver performance in the same controlled manner as simulation is used in studying mechanical vehicle components. The information was supplied by Jeffry A. Greenberg and Thomas J. Park of the Ford Motor Co. Research Laboratory.

[*Automotive Engineering* 1994]
“Driving.” *Automotive Engineering.* September 1994, 14-19.

The role of driving simulation in the vehicle design process at General Motors is reviewed in this article. The article suggests that the GM driving simulator is a viable tool for studies performed in the on-center region of vehicle performance. Additional conclusions and recommendations for using driving simulators are presented. Information for this article was supplied by Gary P. Bertollini, Charles M. Johnson, James W. Kuiper, James C. Kukula, Malgorzata A. Robzveka, and William E. Thomas of General Motors Corporation.

[Bailey 1995]

M. Bailey. *Value of Modeling and Simulation.* An memo by Michelle Bailey to the M&S Benefits Capture Task Force, May 1995.

Bailey writes that the "beef" of M&S "resides in the intelligent and informed application of modeling and simulation to reduce risk, avoid safety/environmental/security issues, and increase the quality of training and equipment." She concludes that M&S is a tool of substantial assistance to the military when properly applied.

[Bailey & Hodak 1994]

S. S. Bailey and G. W. Hodak. *Live Fire Versus Simulation: A Review of the Literature*. NAWCTSD-SR-94-002. Naval Air Warfare Center, Training Systems Division, Orlando, FL, 1994.

The authors reviewed several studies relating to the use of simulation in lieu of live fire for the purpose of reducing the cost of training Marine Corps personnel. Ammunition costs for training Marines range from $1,762 (MOS 03) to $19,145 (MOS 0352--TOW II). Many of the empirical studies have demonstrated that performance with simulation is at least equal to live fire training, but that cost is lower. The Multipurpose Arcade Combat Simulator (MACS) is used to augment training on the M16 rifle and small weapons. Effectiveness studies did not find a statistically significant difference between live fire and simulation, but soldiers with MACS training expended less rounds during live-fire qualifications and fewer soldiers failed to qualify as compared to those trained using traditional methods. The Weaponeer is a part task trainer for training on a variety of weapons, including M16, SAW, M60, AT-4, and M203 grenade launcher. Weaponeer can be used to predict record fire performance, but no data are available on its training effectiveness. The Squad Engagement Training System (SETS) is used to provide marksmanship and tactical training for up to squad level. Several studies have shown positive transfer from SETS to live fire. The Indoor Simulated Marksmanship Trainer (ISMT) is used to train on several small arms and has been demonstrated to benefit live-fire performance. The Precision Gunnery Training System (PGTS) is an inexpensive trainer for the TOW and Dragon missiles, whose rounds are prohibitively expensive ($11,500 and $19,145, respectively, per round) to fire in training exercises. PGTS has been demonstrated to be cost-effective, and also permits training that would otherwise cost several hundred million dollars per year if actual missiles were used.

[Baker et al. 1994]
E. R. Baker, L. Cooper, B. A. Carson, and A. E. Stevens. "Software Acquisition Management Maturity Model (SAM3*)"*. *PROGRAM MANAGER.* Ft. Belvoir, VA, July-August 1994, Vol. 23 (4) 43-48.

This article describes SAM3 and its underlying concepts. SAM3 is a hierarchical structure of Key Process Areas, Key Practices, and Key Indicators. It is organized into five levels of maturity which are: Initial, Repeatable, Defined, Managed, and Optimizing. The acquisition management maturity model is the basis for assessments of the acquisition management capabilities of the organization. This is an excellent article. It provides a clear explanation for a complex model. Graphics add to the presentation and greatly assist the reader in understanding the model.

[Bell & Crane 1992]
H. H. Bell and P. M. Crane. *Training Utility of Multiship Air Combat Simulation. Air Force.* Armstrong Laboratory, Mesa, AZ, 1992.

The authors describe evaluations with developmental DIS systems designed to support multiship air combat training in a combat engagement simulation environment. In the first evaluation, the simulator realistically represented the threat environment (e.g., two F-15 cockpits, visual world, enemy surface to air and electronic jamming, enemy aircraft, pilots and air weapons controllers). Responses of participating pilots and air weapons controllers indicated that they believed that some mission areas were better trained in the simulator than in unit training: multibogey, reaction to SAM, dissimilar air combat tactics, employment of ECM, all aspect defense, escort tactics, all-weather employment, communications jamming, low altitude tactics, threat warning assessment, work with air weapons controller. Mission areas where simulator training was rated inferior to unit training were visual lookout, tactical formation, visual identification, and mutual support.

[Berg et al. 1993a]
R. M. Berg, A. M. Adedeji, and G. W. Steadman. *Simulation Offset to Live Fire Training Phase 2 Results: Application of the at Least Equal Effectiveness Methodology to Simulator Use in Marine Corps Infantry Training Programs*. CRM-93-112. Center for Naval Analyses, Alexandria, VA, 1993.

This study addressed this question: "To what extent does it make sense--from both training effectiveness and cost perspectives--for the Marine Corps to use simulators in performing infantry training tasks that are now done predominantly with live-fire?" The study concluded that third-generation simulators such as Indoor Simulated Marksmanship Trainer (ISMT) can be used cost-effectively in USMC live-fire training programs, that procuring them would be a very good investment, that they would increase the overall quality and effectiveness of training, and significantly reduce the total annual cost of training. The authors recommended that the USMC "proceed expeditiously to implement this type of system into its infantry training programs."

[Berg et al. 1993b]

R. M. Berg, A. M. Adedeji, and C. Trenholm. *Simulation Offset to Live Fire Training Study: Assessment of Marine Corps Live Fire Training Support*. CIM-238. Center for Naval Analyses, Alexandria, VA, 1993.

The USMC has traditionally emphasized live-fire training and placed low priority on acquiring simulators. Anticipated reductions in training resources led to this study of the potential use of simulators in lieu of live training. The study examines simulators currently used in the USMC and Army and the potential for expanded use in the USMC. The training of infantry marksmanship is estimated to be the single most expensive training program in the USMC. M16A2 rifle qualification requires each Marine to fire 250 rounds on the rifle range. The biggest cost driver in marksmanship training is the cost of training ammunition. Additional significant costs are involved in operating and maintaining ranges. Simulators, such as the Multipurpose Arcade Combat Simulator (MACS), have the potential to significantly reduce these costs in the USMC.

[Bessemer 1991]

D. W. Bessemer. *Transfer of SIMNET Training in the Armor Officer Basic Course*. ARI TR 920. U.S. Army Research Institute for the Behavioral and Social Sciences, Ft. Knox, KY, 1991.

Bessemer describes a quasi-experimental assessment of transfer of tactical training from SIMNET to field training. Baseline classes without simulator training were compared in an interrupted time series design to classes with simulator training. Transfer was found using indicators of (1) the amount and type of field training, (2) platoon-level officer leadership performance, (3) overall tactical leadership qualities just prior to graduation. Benefits of simulator training increased in successive classes as instructors learned to train with simulators more effectively.

[Boldovici & Bessemer 1994]

J. A. Boldovici and D. W. Bessemer. *Training Research with SIMNET: Lessons Learned from Simulation Networking*. ARI Technical Report 1006. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1994.

The authors provide a critique of methods commonly used in field experiments to evaluate training systems. In a review of several reports of training effectiveness research as applicable to evaluation of the CCTT, the authors conclude that one-shot empirical evaluations of the kind needed to meet acquisition, test, and evaluation regulations (e.g., AR 70-1, TRADOC regulations 71-9 and 350-4) are costly and often so flawed by compromises in research design that they are unlikely to meet evaluation objectives. Common problems are insufficient statistical power, inadequate sampling, inappropriate analyses, inadequate controls, and lack of control data. The authors recommend that evaluators consider alternatives to empirical evaluations such as in-device learning experiments, quasi-experimental designs, and correlational methods.

[Boldovici et al. 1985]

J. A. Boldovici, D. W. Bessemer, and D. F. Haggard. *Review of the M1 Unit-Conduct of Fire Trainer (*UCOFT*) Validation and Verification Test Report.* ARI Research Note 85-56. U.S. Army Research Institute Field Unit--Ft. Knox, Ft. Knox, KY, 1985.

This review was performed at the request of the then Under Secretary of the Army, James Ambrose. It examines the somewhat mixed evidence contained in the UCOFT V/V test report, and concludes that the UCOFT provided improvements in gunner proficiency on the UCOFT under a number of different conditions, although the V/V did not demonstrate transfer to operational equipment. Substantial gains were found in percents of targets acquired, engaged, hit, and killed for groups undergoing sustainment and transition training. Gains were attributed to improvements in acquisition time, engagement time, and first round hits, which in turn allowed time to scan, acquire, and engage available second and third targets.

[Brown 1992]

F. J. Brown. *Battle Command Staff Training***,** Institute for Defense Analyses, Alexandria, VA, December 1992.

The objective of this paper is to design and develop a new distributed simulation-based intensified training readiness strategy for the Reserve Component. The author introduces "... an innovative prototype for training battle staff synchronization using advanced distributed simulation." This innovative prototype is called Battle Command Staff Training (BCST). Its focus, on the battalion and brigade levels, shows how this new training strategy will positively impact the Reserve Component unit. In their day (late 1970s, early 1980s), these simulation training devices were novel. Today, state-of-the-art is generations beyond the battalion/brigade simulations presented here. This brief paper, with appendices, and supplementary tables addresses the value of distance learning. It asserts that distance learning is the wave of the future. The author proposes BCST as a new model for training. His use of the term "model" refers to structure, rather than a computer program. The simulation-based strategy to which he refers is simply the leveraging of existing battalion/brigade simulations that are used extensively by the Active Component.

[Bryant et al. 1992]

J. A. Bryant, N. L. Lewis, M. Stapp, A. A. Zamarripa, J. Cox, J. Wilhelm, and M. Walker. *JANUS(A) Brigade/Battalion Simulation Cost and Training Effectiveness Analysis*. TRAC-WSMR-CTEA-92-006. TRADOC Analysis Command, White Sands Missile Range, NM, 1992.

This Cost and Training Effectiveness Analysis assessed the command and control (C&C) portion of the Simulator/Simulation-Based Training Program Analysis (SIM2) and the Battalion/Brigade Simulation (BBS) based on analyses and opinion data gathered from SMEs, and supported by a literature review to provide historical data on the simulations. The literature review indicated that JANUS(A) is effective in training company level officers and platoon leaders on current tactics and doctrine and the BBS is effective at the brigade/battalion level. Study results indicated that a large percentage of mission training plan tasks can be trained in the Close Combat Tactical Trainer (CCTT); JANUS(A), BBS, and CCTT have somewhat overlapping, but also individually unique training capabilities. Based on a 15-year life expectancy, the hourly cost of using JANUS(A) was estimated to be $163.

[Brown et al. 1988]

R. E. Brown, R. G. Pishel, and L. D. Southard. *Simulation Networking*. TRAC-WSMR-TEA-8-99. TRADOC Analysis Command, White Sands Missile Range, NM, 1988.

SIMNET effectiveness as platoon-level tactical training device was evaluated by comparing before vs. after training performance results for a SIMNET-trained group with a field-trained control group. Both training groups consisted of four M1 tank platoons. Principal results were that SIMNET training increased field exercise platoon performance, command and control, and leadership, and adequately portrayed vehicle and battlefield sounds. SIMNET was reported to be ineffective for training tasks related to obstacles, dismounting troops, air attack, and use of smoke. The visual display was inadequate for viewing objects beyond 1000 meters and for identifying hull/turret-down defiled positions. The simulated M1 tank speed was unrealistic. SIMNET also improved performance of command and control, platoon movement, leadership, and fire distribution during the company team ARTEP.

[Burnside 1990]
B. L. Burnside. *Assessing the Capabilities of Training Simulations: A Method and Simulation Network (SIMNET) Application*. ARI Research Report 1565. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1990.

Burnside describes a method developed for assessing ARTEP MTP standards that can be met and subtasks and tasks that can be performed when conducting training with TADSS. The method was applied to assess the performance capabilities of SIMNET. Using the criterion that tasks must be at least partially performable to be trainable in SIMNET, the study found that 35% of ARTEP MTP tasks can be trained with SIMNET. The platoon echelon has the highest percentage of trainable tasks (41%) and of tasks not supported by the simulation (46%). The author states that the method provides an efficient means to assess the capabilities and requirements of TADSS.

[Center for Naval Analyses 1995]
Developing a Navy Strategy for Modeling and Simulation: Final Report**.** Center for Naval Analyses Alexandria, VA, March 1995.

This report develops a Navy strategy for modeling and simulation through a series of twenty recommendations regarding Navy modeling and simulation. These recommendations, which are first presented in numerical order with a brief explanation, are then grouped under the areas of the Navy modeling community, distributed simulation, acquisition support, test and evaluation, training, and verification, validation and accreditation. The second grouping includes conclusions, recommendations, and justifications for each of the twenty points. The report presents some valid recommendations in a number of key areas in the modeling and simulation community. Although the report purports a plan of action to achieve each of the recommendations expressed, it frequently provides insufficient detail to validate the recommendation. The summary of key study conclusions discuss the need for centralized coordination of modeling development, the fact that modeling and simulation can contribute meaningfully to the quality of Navy acquisition, test and evaluation, and training. The most meaningful topic for training and education is contained in Appendix E: Training Applications.

[Crane & Berger 1993]
P. M. Crane and S. C. Berger. *Multiplayer Simulator Based Training for Air Combat.* Air Force Armstrong Laboratory, Williams AFB, AZ, 1993.

The authors describe Training Requirements Utility Evaluation (TRUE), a series of simulated air combat exercises conducted in Multiship Research and Development Program (MULTIRAD), a SIMNET-compatible an air combat simulator. TRUE was conducted to identify mission tasks and skills that can be effectively trained using multiplayer simulation. Pilots received training on MULTIRAD and then rated their interest in receiving additional training on each of 30 tasks. The five tasks with the lowest rated interest are primarily visual tasks. Tasks with the highest rated interest can usually be practiced only in large exercises or cannot be practiced except in simulation. It was concluded that multiplayer simulator based training is a valuable training medium for increasing wartime readiness, especially for less experienced pilots.

[Davis 1991]
P. Davis. Letter included in the Congressional Record Volume, "The CFE Treaty" from hearing before the Subcommittee on European Affairs Committee of Foreign Relations, United States Senate, March 20; July 11, 16, 17, and 25, 1991, p. 327 ff.

In a note to the TWSTIAC, Davis recommends the above citation as summarizing his perception of RAND work with simulation and RSAS in affecting the CFE negotiations. Additionally, in a personal opinion in the TWSTIAC NOTE, he points out that the following could be claimed: "(1) Analysis based on simulation-based analysis conflicting with conventional wisdom strongly influenced NATO's insistence on highly asymmetric reductions toward equal ceilings; (2) analysis for OSD clarified the circumstances under which deep reductions would and would not be militarily destabilizing, even with nominal ceilings; and (3) analysis for OSD, supported by simulation-based work, helped clarify and orient the US sense of objectives for confidence and security-building measures." Davis also recommends a paper by Jim Thompson and Nanette Gantz that had a major effect in determining NATO's position in the CFE negotiations. Davis points out that Thompson and Gantz's work, circa 1988, relied on simulation results from RSAS.

[Defense Modeling and Simulation Office 1995]
Defense Modeling and Simulation Office. *Modeling and Simulation (M&S) Master Plan.* Office of the Under Secretary of Defense (Acquisition and Technology), Washington, DC, January 1995.

The M&S Master Plan implements policy outlined in DoD Directive 5000.59, "DoD Modeling and Simulation (M&S) Management." It establishes DoD-wide M&S objectives; provides a comprehensive framework for the programming and budgeting of M&S projects, programs, and activities; and assigns responsibilities for its implementation.

[Defense Science Board 1988]
Report of the Defense Science Board Task Force On Computer Applications to Training and Wargaming. Defense Science Board. Office of the Under Secretary of Defense for Acquisition, Washington, DC, 1988.

This DSB, an advisory committee of senior military analysts chaired by Dr. Anita Jones, focused on the training of joint operational commanders, their staffs, and the commanders and staffs who report to them. The report stated that computer-based, simulated scenarios offer the only practical and affordable means to improve the training of joint operational commanders, their staffs, and the commanders and staffs who report to them. Such decision makers need the opportunity to exercise their decision skills, to test war plans, and to train to work as a closely coordinated force. Increasingly, joint training cannot be conducted in the anticipated theater of operations. There are political objections to disruption of civil activity. The cost of an actual exercise at this level is great. Battle simulation offers the only opportunity to practice the use of certain weapon systems, sensors, tactics, and techniques against a skilled adversary. The report recommended that the CJCS make joint simulations be made interoperable, promote their usage, and establish requirements for future capabilities, a prototype program, and undertake a major joint training initiative.

[Defense Science Board 1993]
Defense Science Board. *Report of the Defense Science Board Task Force On Simulation,* Readiness *and Prototyping.* Office of the Under Secretary of Defense for Acquisition, Washington, DC, 1993.

This DSB, an advisory committee of senior military analysts co-chaired by Dr. Joseph Braddock and GEN Maxwell Thurman, USA (Ret.), focused on the impact of ADS technology on service and joint readiness. The task force declared the belief that ADS technology can greatly improve training and readiness, will help expedite prototyping, and can transform the acquisition process. The belief was based on a judgment concerning confidence. The task force found that the warfighting community has embraced ADS and is extending its utility; warfighters are applying distributed and multiple simulations methods to improve planning, training, and mission rehearsal. They have developed the confidence to use the technology to prepare for war. In contrast, the requirements/development community is using less powerful simulation techniques and the acquisition process is being handicapped.

[Defense Science Board 1994]
Report of the Defense Science Board Task Force On Readiness. Defense Science Board, Office of the Under Secretary of Defense for Acquisition and Technology, Washington, DC, 1994.

This DSB, an advisory committee of senior military analysts chaired by GEN Edward Meyer (U.S. Army, retired), reviewed the state of readiness of the Armed Forces. The report made the following remarks about the relationship of M&S to readiness. Today, modeling and simulation offers great potential as an affordable and effective means by which joint forces can achieve and maintain expertise in operational and tactical tasks, such as employing operational firepower, conducting strategic deployment, employing forces, developing theater intelligence, conducting mission rehearsal, and operational movement and maneuver. In the future, technologies of the "Information Age" offer the prospect of making M&S increasingly more useful in enhancing joint force readiness. Both prudence and economy dictate that DoD capitalize on Advanced Distributed Simulation (ADS) technology to prepare for joint/combined warfare in an uncertain world. ADS can provide the wherewithal for joint task forces, and in particular joint task for staffs, to practice more often and build confidence. Simulations offer the potential for markedly improving joint requirements definition and refinement; joint doctrine development and acquisition; test and evaluation; planning and course-of-action assessments or rehearsals; and military education. Live exercises and training, particularly that conducted on instrumented ranges (e.g., National Training Center, 29 Palms, Fallon, Nellis, etc.), will continue to provide the critical component of unit training. In recent years, however, the Services have exploited modeling and simulation technology to enhance individual and unit readiness while reducing overall training costs.

[Deitchman 1988]
S.J. Deitchman. Preliminary Exploration of the Use of a Warfare Simulation Model to examine the Military Value of Training. IDA Paper P-2094. Institute for Defense Analyses, Alexandria, VA, 1988.

[Deitchman 1990]
S.J. Deitchman. *Further Explorations in Estimating the Military Value of Training.* IDA Paper P-2317. Institute for Defense Analyses, Alexandria, VA, 1990.

[Deitchman 1993]
S.J. Deitchman. Quantifying the Military Value of Training for System and Force Acquisition Decisions: An Appreciation of the State of the Art. IDA Paper P-2881. Institute for Defense Analyses, Alexandria, VA, 1993.

Deitchman reviews the state of knowledge regarding the contribution of collective training in military units to success in battle. The review of the "sparse relevant literature" indicates that unit training under realistic conditions can increase key military capabilities of units from platoon to battalion size (and equivalents in the air forces) by factors of 2 on average. Hardware advances can increase military capability by like amounts if the requisite unit training is also provided. Without the investment in unit training the capability of a military unit should be discounted by about 50%.

[Deluca 1993]
R. Deluca. "Simulator Builders Boost Art in Courting Diversion Seekers". *National DEFENSE*, November 1993, Vol. 128, 492,19-21.

This article focuses on the expansion of traditional defense simulator technologies into the commercial entertainment field and the reasons behind this shift. It sights the finite market of defense simulation sales, the wide-open commercial market, reduced delivery costs, and rapid improvements in hardware and software that make this challenging shift attractive. The article continues by discussing futuristic landscapes, the proliferation of applications, as well as current commercial constraints and solutions to networking problems. The article approaches simulation from a slightly different angle than one would expect to find in *National DEFENSE* magazine; its subject is commercial simulation. It describes the concerns of the commercial simulation industry and the shift toward involvement in the field of entertainment. This article is of interest to those involved in defense simulations and illustrates a direct relationship between defense and entertainment applications.

[Department of the Air Force 1993]
Department of the Air Force Unpublished Manuscript. *Response to Air Force Simulation Questions.* Unpublished manuscript. Washington, DC, 1993.

[Department of the Air Force 1995]
"Simulation and Cost Savings." *Issues in Air Force Simulation and Analysis,* Department of the Air Force. February 1995.

The author proposes that simulation should be used early in the acquisition process in order to "save time, decrease life cycle cost, and decrease risk." The author further states that "the use of prototyping and simulation for the integration of the Multi-mission Advanced Tactical Terminal (MATT) saved between one and three years of acquisition time."

[Department of the Army Operational Evaluation Command 1993]
Study Report: Utility of Synthetic Environments in Support of Operational Test and Evaluation. Department of the Army Operational Evaluation Command, Alexandria, VA, 1993.

This study reports on an experiment conducted by the Army to evaluate the improved capability of the M1A2 tank versus the M1A1 tank and to examine the utility of synthetic environments for support of Operational Test and Evaluation (OT&E). The results of the study support the evaluation of the utility of synthetic environments in support of OT&E pointing out that the existing SIMNET-D/SE is "good enough" for developing maneuver tactics, techniques, procedures, and doctrine. However, there are many limitations within the SIMNET-D that restrict its value for evaluating system capabilities. The Operational Evaluation Command recommends a series of improvements and tasks in order to fully exploit the inherent value of using synthetic environments using SIMNET-D technology.

[Department of the Army 1993]
Simulations and their Relationship to OPTEMPO/Training Ammunition. Department of the Army Information Paper*:* Unpublished memorandum. Washington, DC, 1993.

Virtual simulation is being used to reduce OPTEMPO, typically by reducing flying hours and the amount of training ammunition. An example is flight simulators for Cobras, Chinooks, Blackhawks, and Apaches. Aircrew training manuals permit two flying hours per month to be replaced by simulators. Cost avoidance for the active component due to flight simulators is $68M annually. Fielding of the Conduct of Fire Trainer (COFT) reduced the annual tank main gun ammunition allocation from 134 to 100 rounds. This resulted in an annual cost avoidance of approximately $29M. It was predicted that future fielding of the Tank Weapons Gunnery Simulation System (TWGSS) FY96-001 would further reduce annual ammunition allocations from 100 to 78, an additional cost avoidance of $21M per year.

[Department of the Navy 1993a]
Memorandum for the Director, Force Structure Analysis Division (OSD PA&E): Data Request for Issue Paper: Simulation Support to Readiness. Department of the Navy Unpublished Memorandum. Washington, DC, 1993.

[Department of the Navy 1993b]
*Pacific Fleet and Atlantic Fleet Tactical Training Manual (*TTM**),** CINCPACFLTINST/ CINCLANTFLTINST 3501.1 Department of the Navy. Washington, DC, 1993.

This instruction, referred to as the Tactical Training Manual (TTM), is the single source for tactical training policy and requirements for Pacific Fleet and Atlantic Fleet ships, submarines, aircraft squadrons, and tactical staffs. The manual is to be used by all groups planning or conducting training to ensure consistent training practices throughout the fleets. The TTM consists of six chapters with over thirty appendices that address unit specific training requirements. The most important chapters cover the Tactical Training Strategy, the Training Process, and Measurements and Certification. The Tactical Training Strategy chapter provides a road map to achieve maximum combat readiness and interoperability between the Atlantic and Pacific Fleets. This chapter discusses training philosophy, training responsibilities, tactical training organization, and the tactical training cycle necessary to achieve that objective. The Training Process chapter contains training precepts and training program guidelines for operational staffs, warfare commanders, and individual units. The chapter discusses shore and sea basic training, intermediate training, and advanced training flows. The chapter on Measurements and Certification discusses the training assessment and feedback cycle including establishing training objectives, scenario development, performance criteria selection, data collection plan development, reconstruction and analysis, and performance assessment and feedback. This instruction was written for use by command and training personnel at all levels to ensure a consistent training program. The philosophy of the instruction is well presented for all users, but the most important information is provided in the appendices following chapter 5; that provide specific training cycle information for each ship class and aircraft squadron type, as well as operational staffs and warfare commanders. This information is required for every Commanding Officer and Immediate Superior in Command who wants to adequately plan their unit's training cycle.

[Department of the Navy 1994a]
Surface Force Training Manual COMNAVSURFPACINST/COMNAVSURFLANTINST 3502.2. Department of the Navy. Washington, DC, 1994.

This instruction provides a comprehensive training program that integrates a sequence of individual, team and unit training evolution in all area applicable to the Naval Surface Forces in the Atlantic and Pacific Fleets. It is the primary directive for planning, scheduling, and executing all cyclic and repetitive training requirements within the Naval Surface Forces. There are two significant areas in this instruction that have an impact on modeling and simulation. Chapter two details each phase and step of the Tactical Training Strategy training cycle. This is the same training cycle specified in the Tactical Training Manual. This chapter also describes which phases and steps can be accomplished as shore-based training. The other significant area is Appendix C, Exercise Equivalencies: This appendix provides a matrix of those exercises approved for readiness reporting under the type commander's exercise equivalency program. The exercise equivalency program includes only scenarios run on one's own ship's systems whether generated from shore-based/mobile (van) scenario generators or embedded/on-board scenario generators. The following is a list of the shore based approved scenario generators: TACDEW, ENWGS, CSTS, Mobile Combat Systems Trainer Device 20B4, Mobile Combat Systems Trainer Device 20B5, Radar Video Recorder (RAVIR), LAMPS I/III Mobile Team Trainer Unit (LMTTU), and AN/SQR-17/17A "Rooftop" Transmitter, Device 14E12 (RFTOP). This instruction was written for use by command and training personnel at all levels to properly plan, schedule, conduct, and document training. The instruction provides clear cut guidance on training requirements and acceptable training alternatives. This information is required for every Commanding Officer and Immediate Superior in Command who wants to adequately plan their unit's training cycle.

[Department of the Navy 1994b]
*Threat Training Manual***,** CINCPACFLTINST/CINCLANTFLTINST S3057.1A. Department of the Navy. Washington, DC, 1994.

This instruction is a SECRET supplement to the Tactical Training Manual. The Threat Training Manual provides standardized tools with which trainers and operators can develop widely varying threat scenarios according to their needs. The Threat Training Manual is designed to shift the focus of Fleet Tactical Training from the defunct Soviet Union toward a broad understanding of the other, multi-form threats that US Naval Forces could confront. Complimentary to the Tactical Training Manual, the Threat Training Manual provides a toolbox of potential threat capabilities and tactics that can be used to develop scenarios. These threat scenarios will then be used to support training objectives throughout the Interdeployment Training Cycle that prepares units for overseas deployment.

[DSMC 1994]
Systems Acquisition Manager's Guide for the Use of Models and Simulations**.** Defense Systems Management College Ft. Belvoir, VA, September 1994.

This guidebook is the result of an 11 month Military Research Fellowship program sponsored by the Defense Systems Acquisition Community, and funded by the Defense Modeling and Simulation Office. It provides the acquisition community information on DoD policy regarding models & simulation (M&S) capability and how M&S can be applied throughout the acquisition cycle. It also gives Project Managers an understanding of dual-use technologies, faster and lower manufacturing costs, and complements operational test and evaluation. Simply stated, this guidebook, developed as a reference for the Project Manager, describes M&S policies, types of M&S, applications, and key technical and management issues. The study is organized with a

Preface, eight chapters, and an Epilogue. There are also a number of appendices listing detailed DoD M&S sources. Chapter One introduces the study, explains the purpose, methodology, and objectives. Chapter Two discusses today's applications, systems acquisition process, and requirements generation process. Chapter Three gives a detailed description of DoD M&S, organization, and policy. Chapter Four outlines the classification of M&S to include live, virtual, and constructive. Chapter Five addresses the acquisition life cycle and Chapter Six outlines the issues in the M&S community. Chapter Seven addresses management issues and Chapter Eight looks to the future of M&S. There is an old saying, "You cannot judge a book by its cover." This is certainly true for this study. A more applicable book cover would show the connection between today and tomorrow's war fighting materiel and live, virtual, and constructive M&S. The study is an excellent and comprehensive work outlining DoD's M&S organization and policy. It identifies the key task for the future, which is defining and providing an infrastructure to combine individual M&S into a seamless live, virtual, and constructive world. The study addresses the need for standards for interface definition, communication, representation of environment, management, security, field instrumentation, and performance measurement. While not an objective of this study, a more comprehensive look at user requirements generation, and addressing the merger of combat materiel and training developments models might have been discussed in more detail. The cost of M&S is driving both communities in this direction. The fidelity issue for training versus operational test and evaluation must be addressed. From a cost and proficiency standpoint, separate M&S for each community is unacceptable.

[Fish 1995a]
"Return on Investment Calculations for Indoor Simulation Marksmanship Trainer (ISMT)." Major Dean Fish, MCMSMO, memorandum to M&S Benefits Task Force, 1995.

The purpose of the ISMT is to enhance the combat training of Marines, not replace live fire with simulated rounds. The commander may wish to consider the results of a judicious application of the ISMT to a routine Marine Battle Skill Training (MBST) task (requalification). The offset of just one day of firing results in projected savings of $1.2 million in the first year of the program. In years two through five, projected annual savings are greater than $2.1 million. Complete recovery of acquisition costs is projected before the end of year four; projected cumulative savings at the end of year five exceed $3.2 million.

[Fish 1995b]
"Return on Investment Calculations for Emerald Light: Instrumenting Individual Combat Entities." Major Dean Fish, MCMSMO, memorandum to M&S Benefits Task Force, 1995.

The Emerald Light project potentially offers the Marine Corps a great deal of bang for the buck. The project proposes to instrument portions of the Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms, California. In addition to the instrumentation infrastructure, equipment will be procured for 200 player units including riflemen, tanks, LAVs, and trucks. This instrumented training range will enable improved computer-aided exercises (CAX) at MCAGCC as well as linkage to the Army's National Training Center at Ft. Irwin, California. A Rough Order of Magnitude analysis suggests that Emerald Light could reduce the costs of a CAX from $9.5M to $5.8M. With roughly 10 CAX per year, recovery of investment would be rapid. The improvement in the quality of Marine Corps training, and joint Army-Marine Corps is not quantified.

[Fish 1995c]
"Return on Investment Calculations for Deployable Forward Observer-Modular Universal Laser Equipment (DFO-MULE)." Major Dean Fish, MCMSMO, memorandum to M&S Benefits Task Force, 1995.

The Deployable Forward Observer-Modular Universal Laser Equipment (DFO-MULE) is a deployable, modular, DIS compliant, PC-based system that provides basic, advanced and sustainment training for Forward Observers and Forward Air Controllers. Fire support operations involving Naval Gunfire, Artillery, and Close Air Support are simulated on this system. Assuming a 10% offset of live fire tasks, savings in ammunition expenditures realized by DFO-MULE can potentially recover the acquisition costs before the end of the second program year. The most expensive round, the $36,087.68 Copperhead, is excluded from the calculation. Several qualitative advantages are also cited.

[Frost & Sullivan 1989]
Frost and Sullivan *The US Military Trainer and Simulator Market, Vols. I and II.* Frost & Sullivan, Inc. January 1989.

This is a two volume comprehensive report based on studies conducted by Frost & Sullivan. This report is in nine sections, a Table of Contents, and an Appendix. Each section is further divided into subsections providing even more detail. Section One is the Executive Summary which provides a forecast of the US military market for simulators and other training devices (FY 90 - FY 94). The Executive Summary also lists top companies in this market (FY 83 - FY 88) and provides a synopsis for the entire report. Section Two introduces the report's overall objectives, definitions, organization, coverage, sources of data, application, and scope. Section Three gives the background information. Sections Four, Five, and Six discuss each service's simulators and training devices; planned procurement; research, development, testing, and evaluation (RDT&E); competition; and contracts and forecasts. Section Seven summarizes the

market for training devices related to the military market but funded by other agencies. Section Eight discusses technological trends. Section Nine profiles manufacturers of military simulators and other training devices. There is a useful Glossary in the Appendix. This 500+ page report provides detailed information regarding trainers, simulators, and associated markets. While trainers and simulators may play a vital role in the conduct of a wargame model simulation, there is a distinct difference between trainers and simulators, and wargames, models, and simulations. Although it does not address wargames and simulations and should not be used as a source document to evaluate trends or markets in that area, this report is well organized provides the reader with a range of detail, from executive overview to service specific programs and listings of individual devices. The format of this report makes it easy to focus on a specific area of interest bypassing those sections of little interest to the reader. Sections Four, Five, and Six, containing the service's training devices, make up the majority of this report. These sections are detailed and do provide qualitative and quantitative information pertinent at the time this report was prepared. Overall, a great deal of data is in a readable and understandable format.

[Garcia et al. 1994]

A. B. Garcia, R. P. Gocke, N. P. Johnson. *Virtual Prototyping: Concept to Production*. Defense Systems Management College, F. Belvoir VA, March 1994

This study represents the combined efforts of three military Research Fellows participating in an 11-month Senior Service College Research Fellowship program. It is designed to provide a forum for the conduct of research in a subject of vital interest to the US defense acquisition community. The research that supports this study was conducted during calendar year 1993. Simply stated, this study assesses and describes the current state of virtual prototyping. It focuses on leveraging virtual reality to "build" prototypes with computers, test their performance in a synthetic battlefield, conduct trade-off evaluations between existing/modified/new systems, all before the actual construction of a prototype. The study is organized with an Executive Summary and six chapters. The introduction, Chapter One, explains the objective, methodology, assumptions, and background of the study. Chapter Two explains the defense environment and the role of virtual prototypes. Chapter Three addresses the spectrum of synthetic environments. Chapter Four examines the application of synthetic environments to the acquisition process. A detailed account of synthetic applications is given in Chapter Five, while Chapter Six presents the study's summary and recommendations. There are useful appendices that list virtual prototype models and simulations, the points of contact of each, a glossary, and a bibliography.

The body of literature on virtual prototyping is without extensive references to current applications in the defense industry; not because it is not being used, but because each company considers virtual prototyping a key ingredient of their ability of compete. Thus they jealously protect the specifics of how they use virtual prototyping. As an example, Boeing developed its newest commercial aircraft, the Boeing 777, without building a physical mock-up. The digital prototype was designed and tested, then went straight to the design floor for construction. Boeing will not share its "how to" use of virtual prototyping. Throughout the text there are two tables, 71 figures, and ten color plates that make this otherwise difficult subject more understandable. The large type, two-column per page format makes the text easy on the eyes.

The study's literature review identified more than 500 articles of possible relevance. Ultimately, 150 of these sources were actually used in the preparation of the study and 113 are cited in the bibliography.

[Gates 1987]
S. M. Gates. *Appropriate Mix of Live Fire and Simulated Fire During Training.* CNA CRM 87-116. Center for Naval Analyses, Alexandria, VA, 1987.

Gates presents a small-scale review of studies to estimate the general benefits of TADSS and live fire to develop weapon system operator proficiency. General conclusions are that training with simulated fire can develop the same skills as live fire, an increase in simulator practice time can translate into higher levels of operator proficiency, and only minimal amounts of live fire may be required to effect transfer of simulator training. As simulator training becomes more effective, more live fire practice can be replaced without degrading operator proficiency, but a certain amount of live fire will probably always be recommended to document the training transfer and convince the gunner that he is in fact a capable weapon system operator and not merely an expert at a realistic video game.

[General Accounting Office 1993]
Army Training: Commanders Lack Guidance and Training for Effective Use of Simulations. General Accounting Office. Washington, DC, 1993.

This study was conducted in response to a tasking from the Committee on Armed Services, House of Representatives, which stated, in part, "The Army faces many constraints on the field training exercises that it has traditionally used to prepare its forces for wartime missions. funding for the ammunition, fuel, and maintenance required for these exercises has been reduced, and environmental concerns restrict the use of ranges and maneuver areas. In response, the Army has turned to simulations to supplement field training exercises." The report noted that at the brigade level and above, simulations can be used to improve the decision making skills of senior battle officers before they command units in large scale training exercises and that at the lowest level, simulations can be used to develop the basic skills of individual soldiers. Exemplary simulations cited in the report were COFT, used on tanks and Bradley Fighting Vehicles; MILES, used to simulate direct fire weapons from rifles to tank and helicopter gunnery systems; and SIMNET, used to provide crew-, platoon-, and company-level training. The report concluded that though simulations are not reaching their full potential because commanders lack adequate guidance and training in their effective use.

[General Accounting Office 1991]
Army Training: Computer Simulations Can Improve Command Training in Large-Scale Exercises. General Accounting Office. Washington, DC, 1991.

This study was motivated by concern over whether simulation provides an adequate alternative to traditional large-scale military exercises. The GAO analyzed the 1990 REFORGER exercise, in which extensive use was made of simulation, fewer U.S. troops participated, and emphasis was given to training staffs and leaders at higher organizational levels rather than lower level units. Training for higher echelon leaders, such as at brigade, division, and corps, was made possible by extensive use of computer-assisted simulation. It was reported that a consensus exists among many military officials that computer-simulated exercises, such as REFORGER, offer the potential for effective training, particularly at higher organizational levels, where the focus is on battle planning and command and control. Benefits of such training were emphasis on battle planning, staff procedures, and command and control; more efficient use of training time; enabled a focus on higher echelons that would otherwise be cost prohibitive; lessened adverse environmental and political impacts. The 1990 exercise saved more than $4M in transportation and cargo handling costs as compared to costs historically. However, the study noted that comparing the costs of traditional and simulation-based exercises may not be meaningful because of differences in the type of training provided.

[Gorman 1990]
P. F. Gorman. *The Military Value of Training.* IDA Paper P-2515. Institute for Defense Analyses, Alexandria, VA, 1990.

This paper was prepared in response to a NATO inquiry seeking to apply operational research to the contribution of military training and the overall effectiveness of the force. It presents the training vision of General Gorman, a former commander of the US Army 8th Infantry Division. At a time when requirements for readiness were increasing and training resources were decreasing, he was among the first to introduce battle simulation to train and evaluate tactical Army units. This publication is now dated and of little value to researchers looking at current technology and R&D for future applications. However, this paper is of value to historic researchers of the early years of simulations or those looking for basic simulations applicable at the tactical level of combat unit training. General Gorman, considered one of the “founding fathers” of training simulations, has written an easily understandable study.

This document is a primer on the use of training simulations at the tactical level and the author's architectural framework for training continues to be followed today. General Gorman writes, "The first battle of most wars fought by the Army of the United States was a disaster: a costly defeat or a Pyrrhic victory." This quotation is a timeless argument in favor of simulated training that is resource effective and can be rehearsed repeatedly to improve combat readiness, refine necessary skills and strategies, and preserve the fighting forces. Gorman presents compelling evidence concerning the value of combat experience for survival and later success in combat and makes the case that tactical engagement simulation provides the military with the equivalent of combat experience without its casualties. During World Wars I and II, inexperienced pilots had at best four chances out of ten of being shot down and fewer than 15% of pilots had a better than 50% chance of surviving their first combat. But with each successive victory, a pilot's survivability increased dramatically. A NATO review of German U-boat captains showed that 10% of them accounted for 45% of recorded sinkings. Early success in combat was correlated strongly with survivability. During the early years of the Vietnam war, about one U.S. fighter was lost for every two North Vietnamese MIGs; the ratio of victories to losses rose to 12.5:1 for Navy pilots after the Top Gun program, an engagement simulation, was established.

[Grimes 1994]
V. P. Grimes. "Navy/Marine Corps Team Changes Training Focus." *National DEFENSE*, November 1994, Vol. 129 (502) 26-27.

This article details simulations systems marketing trends in the Navy and Marine Corps. It provides readers with basic knowledge of training trends in the Navy Department triggered by changes in the threat, budget constraints, and joint training/operations commitments. There are enough facts and figures in this two-page article to give the reader a basic knowledge of Navy and Marine Corps training trends as well as reasons for the direction training has taken in these services. It covers areas such as Zero-based Training and Educational Review, systems trainers, littoral warfare environment, and organizational changes in just enough detail to provide an outline of the naval services' training initiatives.

[Hammond et al. 1993]

M. H. Hammond, D. R. Graham, and E. P. Kerlin. *The Role of Distributed Simulation in Defense Acquisition.* IDA Paper P-2902. Institute for Defense Analyses, Alexandria, VA, 1993.

[Horowitz et al. 1992]

S. Horowitz, C. Hammon, P. Lurie, P. Brooks, and A. Rolfe. *The Cost-Effectiveness of Flying Hours and Simulators.* Briefing. Institute for Defense Analyses, Alexandria, VA, 1992.

The authors gathered and analyzed data relating to flying hours and simulator time and mission performance or safety. More than $10B per year is spent on flying hours but the appropriate mix of flying time and simulator time is unclear. A general conclusion from several different studies is that both flying hours and simulator time affect performance, but usually career flying hours have a greater effect than recent flying hours. Bombing and air drop accuracy data indicate that additional simulator hours seem to have a greater effect than additional flying hours, and simulator hours cost at most a third as much. Helicopter accident data indicate that both flying hours and simulator hours reduce accidents, but simulator hours do not increase expose to risk. The authors suggest that it may be cost-effective to substitute small amounts of additional simulator time for flying time, but note that measures of proficiency used in analyses were incomplete and were wary of carrying this too far.

[Houck et al. 1991]

M. R. Houck, G. S. Thomas, and H. H. Bell. *Training Evaluation of the F-15 Advanced Air Combat Simulation*. AL-TP-1991-0047. Air Force Armstrong Laboratory, Williams AFB, AZ, 1991.

The evaluation investigated the utility of existing multiship simulation for training air combat tasks. F-15 pilots and air weapons controllers participated in four days of training in simulated air combat missions in an unrestricted combat environment that included multiple air and ground threats, electronic warfare, and real-time kill removal. After training, participants rated the value of training. Overall, participants indicated that simulation enhanced their combat readiness and was more beneficial in some areas than traditional unit training.

[Hughes et al. 1988]

C. R. Hughes, W. G. Butler, B. S. Sterling, and A. W. Berglund. *M1 Unit Conduct of Fire Trainer: Post* Fielding *Training Effectiveness Analysis.* TRAC-WSMR TEA 16087. TRADOC Systems Analysis Activity, White Sands Missile Range, NM, 1988.

This analysis evaluated the training effectiveness of the M1 UCOFT. The evaluation included 369 tank commander-gunner pairs from six armor battalions in Europe. Training effectiveness was evaluated in terms of crew performance on tank table VIII. Results were (1) progress through the training matrix and, to some extent, more training time typically resulted in improved table VIII performance; (2) the UCOFT is not a precise predictor of performance; (3) the UCOFT can make a substantial contribution to sustaining crew gunnery skills; (4) users felt that the UCOFT improved home station gunnery training.

[Hughes(ed.) 1989]

W. P. Hughes(ed.). *Military Modeling (Second Edition).* Military Operations Research Society, Alexandria, VA ,1989.

This textbook, used at the US Army War College with endorsement of the Military Operations Research Society (MORS), describes the attributes of well-conceived military models, shows how models can contribute to the decision process, and cautions the reader that models can be misused and oversold. It is designed for the reader who is knowledgeable in military operations and the decision-making process, but who has only superficial acquaintance with the models that inform and contribute to the process. For the subject matter expert, *Military Modeling* serves as the primer for military modeling. The book begins with an Overview, written specifically for the novice and proceeds to introduce the student to the subject of modeling with general readings in 15 technically-based chapters. This work describes military models across all dimensions. It is designed and written for senior individuals who are entering the field of military modeling. It serves as the transition piece from those who know about modeling to those who are expert in the field. The contributing authors represent leading practitioners of military modeling. Of note is the discussion of models' verification and validation; these often misunderstood concepts are examined in depth, clarified, and defined. For example, the author notes that all models are, by definition, invalid because they are, after all, abstractions of an actual activity. In addition to abstraction, which is the omission of some observable factors, there is another concept that effects models: approximation. Approximation involves limits on the precision of calculation. The better the modeler is able to reduce the influences of abstraction and approximation, the better the model.

[Irvine 1994]

G. M. Irvine. *Combat Training Can Be Done Pierside.* Naval Institute Proceedings**,** US Naval Institute, Annapolis, MD, January 1994, Vol. 120 76-79.

This article describes the advantages of on-board training with a ship's own hardware using either the SQQ-89 Onboard Trainer (OBT) or an Interface Test Set (ITS) to provide training inputs. The article highlight exercises from 1992 and 1993 that used this training effectively. This article provides an excellent summary of the exercises during this time period that demonstrated the effectiveness and efficiency of training in port using simulation and training devices in conjunction with a ship's own systems. This study demonstrates the uses of simulation in education and training today. It is a good source of examples which would lend credence in the classroom.

[Institute of Simulation & Training 1995]

12th DIS Workshop on Standards for the Interoperability of Distributed Simulations, Volume 1 Position Papers. Institute of Simulation & Training, Orlando, FL, 1995.

This document is a compendium of 101 technical papers presented at the 12th DIS Workshop. It represents the very latest thinking for current distributed interactive simulation technology and innovation. The 15-page Table of Contents lists all titles, authors' names and organizations. A sampling of some of the more provocative titles includes: "Strategies for Scaling DIS Exercises Using ATM Networks," "Qualitative and Quantitative Comparison of Images from Dissimilar Image Generators in Distributed Visual Simulation," "DIS Synthesis With Interactive Television: Revolution of the Educational Paradigm," and "An Algorithm for Presenting a Continuous After-Action Review Representation from Multiple Overlapping DIS Exercise Segments."

[ITEC 1995]

International Training Equipment Conference and Exhibition Proceedings. Complied by N. Jackson and N. Cruz. April 25-27, 1995. The Hague: ITEC, Ltd. 1995.

This work contains papers and reports from the International Training Equipment Conference and Exhibition Proceedings held in The Hague, The Netherlands April 25-27, 1995. Works are submitted under the general headings as follows: Training Performance, Driving Simulation-Technical, Driving Simulation-General & Applications, Unseen Services To Aviation, Synthetic Environment, Distributed Interactive Simulation Technologies, Computer Generated Forces-Environment, Distributed Interactive Simulation, Audio-Visual Cues, Multimedia Training Requirements, Airline Training, Flight Training Organisation, Aviation Training, Virtual & Constructive Simulation, Computer Based Training Applications, Simulation Training & Equipment, Combat Training, and Maritime Training.

[Jolly and Ward 1995]
A. C. Jolly and R. C. Ward. *Cost Saving/Avoidance Benefits of Hardware-in-the-Loop Simulation and Distributed Interactive Simulation at RD&E Center, US Army Missile Command*. Research, Development, and Engineering Center, US Army Missile Command. Redstone Arsenal, AL. 1995.

Jolly and Ward's report contains the details of the outcomes of selected use of Hardware-in-the-Loop (HWIL) and Distributed Interactive Simulation (DIS). They provide some examples of demonstrated benefits in cost savings and cost avoidance experienced in missile development programs supported by the Research, Development, and Engineering Center (RDEC).

[Kraemer & Bessemer 1987]
R. E. Kraemer and D. W. Bessemer. *U.S. Tank Platoon Training for the 1987 Canadian Army Trophy (CAT) Competition Using a Simulation Networking (SIMNET) System.* Research Report 1457. U.S. Army Research Institute for the Behavioral and Social Sciences, Ft. Knox, KY, 1987.

The authors estimate the effects of SIMNET training based on observation and interviews, results of CAT competition, potential relationships between CAT results and SIMNET training with other unit training. Findings suggest that SIMNET training may have helped units develop and improve their fire control distribution plans and helped unit leaders develop the C^3 skills to effectively execute those plans during platoon battle runs. Other major contributing factors to CAT outcomes were conducting live fire battle runs and tank crew gunnery training on the M1 UCOFT. The most apparent shortcoming of the SIMNET that may have interfered with CAT training was in the M1's fire control system.

[Lane and Alluisi. 1992]
N. E. Lane, and E. A. Alluisi. *Fidelity and Validity in Distributed Interactive Simulation: Questions and Answers.* IDA Paper D-1066. Institute for Defense Analyses, Alexandria, VA, 1992.

[Nance et al. 1994]
J. F. Nance, R. P. Neisler, G. W. Steadman, and B. Wilhoite. *Simulation Offset to Live Fire Training: Test Plan Phase 3.* CIM -344 (AD-B186-338L). Center for Naval Analyses, Alexandria, VA, 1994.

[National Simulation Center 1994]
Training with Simulations: A Handbook for Commanders and Trainers. National Simulation, Center Combined Arms Center, Fort Leavenworth, KS, October 1994.

This US Army Command and General Staff College (CGSC) text was written for commanders and trainers to assist them in the planning and conduct of exercises involving simulations. It is designed to provide the reader with a basic introduction to simulations, a glossary of terms,

insight into how C2 training simulations may be incorporated into an overall training strategy, specific guidance for their use in the development of a unit training strategy, general guidance into the planning of training exercises, and a view of future prospects in the area. *Training with Simulations* consists of fifteen chapters with seven appendices as well as a Glossary of Abbreviations and Terms. The National Simulation Center (NSC) prepared this book to meet the varied intellectual requirements of a primary and a secondary readership. *Training with Simulations* adequately serves as the primary textbook for a CGSC course and as reference material for non-training personnel engaged in C2 training simulations development. Although technical material is included to insure thoroughness of the topics presented, it would be wrong to characterize this book as a technical document. By design, the National Simulation Center assumed the readers would possess very little inherent knowledge of the general subject of simulations. The text offers a basic foundation of the topic in straight-forward language including a measured assortment of details that serve to clarify rather than distract. In the initial pages, this book removes a common confusion concerning the differences between simulations, models, simulators, and the varying types of models and simulations. Thereafter, the book continues to be a helpful training aid. The book is well organized for those new to the field and who seek to develop a strong point of departure for further reading or course work in simulations: Part I establishes a foundation in simulations, Part II addresses the question, "why do we have simulations in the training environment?", Part III discusses a number of simulations currently available in the Army as members of the "Family of Simulations," Part IV presents the relationship between basic Army training principles and the employment of training simulations into a simulations strategy, and Part IV is divided into two major chapters that discuss developments to the year 2012. The organization of the textbook is pedagogically sound and makes the learning process for an individual, new to this complex field, easy and approachable.

[Noble & Johnson 1991]

J. L. Noble, and D. R. Johnson. *Close Combat Tactical Trainer (CCTT) Cost and Training Effectiveness* Analysis. TRAC-WSMR-CTEA-91-018. TRADOC Analysis Command, White Sands Missile Range, NM, 1991.

This CTEA addressed the training capabilities and cost-effectiveness of the CCTT, a simulator intended to train armor and mechanized infantry crewmen. The analysis concluded that the CCTT has the potential to train tasks relating to command, control, and communication; maneuver and navigation; and teamwork and leadership; and, to a lesser degree, certain procedures related to gunnery, target acquisition, and driving. The analysis projected that the CCTT, when fielded, would be cost-effective and that its life cycle costs would be paid back fully during its service life when acquired at either battalion or company level.

[Null et al. 1993]
C. H. Null, and J. P. Jenkins(eds.). *NASA Virtual Environment Research, Applications, and Technology*. National Aeronautics and Space Administration, *October* 1993.

This White Paper describes the environmental research technology and its applications in NASA Centers, the potential roles it can take in NASA, and a strategic plan for NASA in the next five years. Virtual Environment displays are interactive, computer graphics-based, and head-referenced and create the illusion the user is remoted to another location. The White Paper contains a four-page Executive Summary, the Strategic Plan, and numerous one- or two-page listings of programs, research, and applications currently in use at NASA. Each listing provides a description of the system capability, system status and future plans, system architecture, location, point of contact, e-mail address, voice and fax telephone numbers, and the offices with which coordination has been conducted. NASA has contributed to the current body of literature with this White Paper. It represents an overview of the entire NASA virtual environmental effort and affords the reader a single-source document from which to initiate research. The simulations described in this White Paper are sophisticated, state-of-the-art programs. The applications are not only current, but demonstrate futuristic overtones.

[ODUSD(R) 1995a]

Military Manpower Training Report: FY 1996. ODUSD(R) (Office of the Deputy Under Secretary of Defense for Readiness). Washington, DC, 1995.

[ODUSD(R) 1995b]

Use of Simulation in DoD Training. ODUSD(R) (Office of the Deputy Under Secretary of Defense for Readiness). Washington, DC, 1995.

This study was conducted in response to a Congressional request to DoD to determine the capabilities and limitations of simulation for training, its impact on training, DoD investments, and whether cost savings were possible though increased use of simulation. Some key findings are as follows. Regarding capabilities, simulations cost much less to use than operational equipment and can result in significant economies in training; enable people to do things that would otherwise be impossible, such as realistic simulations of combat and mission rehearsals; enhance safety, because they can be used to do things that are too dangerous to practice with operational equipment; in some cases, provide performance data and better feedback to users than the systems they represent; overcome the practical limitations of live training, such as presenting a large force in a 360-degree battlefield; and help overcome environmental restrictions, which limit the ability to perform certain types of combat training, such as electronic warfare and realistic weapons employment training. Regarding limitations, the report indicated that simulations have a limited capability to represent the complex conditions involved in tactical aviation, such as the acceleration forces resulting from high-speed maneuvers and concomitant problems associated with spatial-temporal awareness; can cause a type of disorientation known as "simulator sickness" if visual and motion cues are not carefully synchronized; and still have technical hurdles to overcome in order to create a "seamless synthetic environment" capable of including all combat forces and platforms. Technical challenges include developing a common architecture, authoritative representations of environments and human behavior, and the full spectrum of weapon systems simulation. Simulation has proved to be both effective and efficient in providing training for a wide variety of tasks. The next generation of simulations presents opportunities for greater cost savings, but continuous and systematic feedback on the cost, effectiveness, and limitations of M&S technology is critical in developing successful strategic policies, plans, and investments strategies.

[Office of Technology Assessment 1994]

Virtual Reality and Technologies for Combat Simulation. Office of Technology Assessment. United States Congress, Washington, DC, 1994.

This analysis reviewed the state of the art of virtual reality (VR) technology for combat simulation, and made a number of observations on its cost-effectiveness currently and in the future. Cost-effectiveness is increasing as integrated circuits increase in density. The number of transistors in microprocessors is doubling every two years, the information storage capacity of memory chips is increasing similarly, and CD ROMs and other media are now commonly used for high-capacity storage. Significant improvements are being made in several technologies supporting virtual reality (e.g., flat panel display chips, LCDs, micromechanical mirror arrays, parallel processing, networking, improved software) and together these will allow new simulators to improve their speed and realism. Newer, high-density chips reduced the average cost of a fully immersive virtual reality system (with head tracking, head-mounted display, and three-dimensional sound) from $100K in early 1991 to about $50K in 1993. It is forecast that cost will continue to decline. Similar trends are apparent in other computer-intensive simulators. High-tech simulation technology continues to become increasingly cost-effective. VR challenges today include developing improved high-density, color flat-panel displays; fast head tracking; wideband networks with low latency; multilevel network security; automating object and world description for scene generators; simulating infantry and noncombatants.

[Operational Research and Analysis Establishment 1990]
Comparison of Conventional and Simulator Enhanced Tank Gunnery Training Methods. Operational Research and Analysis Establishment. Project Report 523. Ottawa, Canada, 1990.

The report describes a series of war games performed with the JANUS simulation model to determine how training with M1 UCOFT would influence combat effectiveness. Tank gunners trained with UCOFT fired their opening rounds about 25% faster than conventionally trained gunners. Based on estimated combat effectiveness, UCOFT training appeared to be of little, if any, benefit for LEOPARD C1 tanks when opposing heavily-armored probable threats. When the model used LEOPARD II or M1A1 tanks, UCOFT trained gunners killed significantly more opposing tanks than conventionally-trained gunners. The difference in combat effectiveness is the result of the relatively greater firepower and survivability of LEOPARDII/M1A1 as compared to LEOPARD C1.

[Orlansky 1993]
J. Orlansky. *The Battle of 73 Easting and Ways to Future Victories*. NATO Panel 8 Meeting on Training Strategies for Networked Simulation and Gaming, NATO, November 1993.

"73 Easting" is a location in the Iraqi desert where the U.S. Second Armored Cavalry Regiment fought elements of the Iraqi Tawakalna Division. The battle occurred on the second day of the four day ground war. The U.S. troops were outnumbered three to one but destroyed the opposing force, a heavy brigade in deliberate defense of an area the Iraqis had used for training exercises. In February 1992, some of the men who participated in the battle came to Washington to review and correct the record of the battle. Two retired officers asked them the following question: "None of you have ever been in combat before. How do you explain your great success in your first battle?" Battle participants responded, "Sir, this was not our first battle. This was our 15th battle! We fought three wars at the National Training Center (NTC), Fort Irwin, California, four wars at the Combat Maneuver Training Center (CMTC), Hoenfels, Germany; and a lot of other simulations like SIMNET, COFT, and BCTP. Yes, sir, we had been 'shot at' before. Many times. This war was just like out training."

[Orlansky et al. 1994]

J. Orlansky, C. J. Dahlman, C. P. Hammon, J. Metzko, H. L. Taylor, and C. Youngblut. *The Value of Simulation for Training.* IDA Paper P-2982. Institute for Defense Analyses, Alexandria, VA, 1994.

This study examines the utility of simulation for training at individual, unit, and joint force levels. The cost-effectiveness of flight and maintenance simulators is well established, but a relatively limited amount of work has been done to establish the cost-effectiveness of simulation for more advanced individual training in units or for collective training at units or in units for component or joint training. Available findings are that simulators are cost-effective for initial flight and maintenance training in institutions: they train as well as actual equipment and cost less to procure and use. This finding also applies to CBI as compared to traditional classroom instruction. Simulators are a good investment.

[Orlansky & String 1977]

J. Orlansky, and J. String. *Cost-Effectiveness of Flight Simulators for Military Training Volume I: Use and Effectiveness of Flight Simulators*. IDA Paper P-1275. Institute for Defense Analyses, Alexandria, VA, 1977.

The operating cost of flight simulators is estimated to be between 5-20% of the cost of aircraft. Many studies have shown that skills learned in flight simulators can be performed successfully in aircraft; the use of simulators for training can reduce flight time. At the time of this study, the cost-effectiveness of flight simulators had been reported in only a few studies and their primary use was in undergraduate flight training; their greatest potential for future savings lay in transition and continuation flight training.

[Orlansky et al. 1984]

J. Orlansky, M. I. Knapp, and J. String. *Operating Costs of Aircraft and Flight Simulators.* IDA Paper P-1733. Institute for Defense Analyses, Alexandria, VA, 1984.

This paper summarizes data comparing the operating cost of flight simulators and aircraft. The median cost ratio of simulators to aircraft was 8%.

[Orlansky & String 1981]

J. Orlansky, and J. String. *Cost-Effectiveness of Maintenance Simulators for Military Training.* IDA Paper P-1568. Institute for Defense Analyses, Alexandria, VA, 1981.

This study found that maintenance simulators are as effective for training as actual equipment trainers when measured by student achievement in school. Acquisition cost of simulators is typically less than actual equipment trainers. In the majority of cases examined, the cost to develop and fabricate one unit was less than 60% of actual equipment and the cost of fabricating a second unit was less than 20%. It was estimated that the acquisition and use of a maintenance

simulator over a 15-year period would cost 38% as much as actual equipment. In studies where time to train was reported, simulators took 25-50% less time than actual equipment.

[Oswalt(ed.) 1993]
J. Oswalt. Simulation *& Gaming*. An International Journal of Theory, Design and Research SAGE Publications Inc. June 1993, Vol. 24 (2).

This special edition publication, a compendium of articles, summarizes recent military simulation and gaming applications, trends that affect their use, characterization and criteria of evaluation, and factors impacting their development (technologies, standards, and requirements). It also describes current organizations and implementations within the military services, academic institutions, and commercial enterprises. It concludes with a discussion of issues in combat simulation. "Current Applications, Trends, and Organizations in US Military Simulation and Gaming" is a review of military simulation and gaming. The next two articles, "Principles for the Design and Selection of Combat Simulations" and "Flexible Combat Modeling," are much more focused. The article, "Flexible Combat Modeling," is of particular interest to the DMSO Education Study. The author not only discusses the contemporary period, but postulates about what will constitute necessary flexibility in the future. He also includes a brief section at the end entitled, "Advancing the State of the Art." Here he suggests two areas for research and design. The first is the ability to represent the differences among theaters of operation and forces that might participate in them. This effort requires defining how conflict would likely vary by region and then determining how models would need to be adjusted to reflect such differences. A consistent set of assumptions is yet to be designed in this arena. The second area is the representation of new technologies. The author argues that new technologies or threats have been entered into models without adjusting the strategy or operations of either side, leading to significant, but questionable, effects on the overall combat outcomes. Overall, a systematic assessment of such changes in combat environment has not been performed by the military analysis community. These articles are reprinted from earlier publications.

[OSD 1994]
"Task Force on the Use of Modeling and Simulation in Test and Evaluation." OSD USD (Acquisition and Technology), Washington, DC, 23 June 1994

This report responds to the Defense Authorization Report for FY 94 regarding the use of Modeling and Simulation in Test and Evaluation. The response is structured in two sections consisting of (1) a description of the Department's policy regarding modeling and simulation investment and a progress report on implementation and (2) a discussion of the analytical basis the Department and the services have used as an investment strategy. Appendix A reflects where modeling and simulation has realized cost savings or cost avoidance.

[Randel et al. 1992]
J. M. Randel, B. Morris, C. D. Wetzel, and B. V. Whitehill. "The Effectiveness of Games for Educational Purposes," *Simulation and Gaming, 1992, Vol. 23 (3)* 261-276, (AD-A259-666).

[Regian et al. 1992]
J. W. Regian, W. Shebilske, and J. Monk. "A Preliminary Empirical Evaluation of Virtual Reality as Instructional Medium for Visual-Spatial Tasks." *Journal of Communication*, 1992, Vol. 42 (4) 136-149.

[Pfeiffer & Dwyer 1991]
M. G. Pfeiffer and D. J. Dwyer. *Training Effectiveness of the F/A-18 Weapon Tactics Trainer (Device 2E7).* NTSC TR 91-1008. Naval Training Systems Center, Orlando, FL, 1991.

This study is a training evaluation of Device 2E7, F/A-18 weapon tactics trainer. Four maneuvers were examined, two each involving air-to-air and air-to-ground weapons delivery/tactics. Device 2E7 was effective for achieving learning objectives; skill acquired on the device transferred to the F/A-18 aircraft for each of the four tasks examined.

[Schwab & Gound 1986]
J. R. Schwab, and D. Gound. *Concept Evaluation of Simulation Networking (SIMNET).* TR 86-CEP345. U.S. Army Armor and Engineer Board, Ft. Knox, KY, 1986.

This early study of SIMNET was conducted to evaluate its capability to support platoon level command and control exercises to train individual and collective tasks. Three of the four platoons in each group, SIMNET and baseline, improved their performance between the first and second set of STXs. The SIMNET group improved from an average of 73% GOs on the pre-training STX to an average of 84% on the post-training STX. The baseline group improved from 59% to 65% pre- to post-training. The SIMNET group had a higher average score after both pre- and post-training STXs. The SIMNET group improved their average group score by 13% while the baseline group improved its score by 6%. Test players expressed the opinion that SIMNET was useful at training platoons in troop leading procedures, command and control, land navigation, and teamwork. They cited the ability to place platoons being trained throughout an exercise as one of the systems advantages.

[Seidel and Chatelier(eds.) 1993]
R J. Seidel and P R. Chatelier(eds.), *Advanced Technologies Applied to Training Design***,** Plenum Press, New York, NY, 1993.

This is a collection of papers that is the product of a workshop sponsored by NATO's Defense Research Group Panel 8. The Group's overall purpose is to stimulate the defense application of research through the active exchange of information among the NATO member nations. Panel 8 identifies training technologies that will maintain a capable and ready force during periods of

reductions in military force structure and budgets. The workshop participants seek to leverage opportunities to apply these training technologies to nonmilitary roles of the future. The workshop focused on six technological areas: Authoring Systems; Models, Embedded Training and Simulation; Advanced Hardware Technology; Use of the Cognitive Approaches; and Expert Systems. The workshop also considered existing data structures that can provide both researchers and practitioners with ready sources of information. Authoring Systems is a high cost driver for the most important factor of effective education and training. The workshop examined computer aided techniques that offer alternatives to overcome this dilemma. The technological revolution in training is addressed in the next three sections. Models offer various solutions to reduce error from variations in approach, offer standardized formats, and provide interoperability for training and education. Embedded training and simulation offer the training managers alternatives to purchasing expensive military equipment. Advanced Hardware Technology is the critical, often limiting, factor that this workshop addresses. Experience has shown that software advances often outpace hardware advances. The focus on cognitive approaches helps the participants understand the latest theoretical underpinnings to improve and further design improvements. The last section, Expert Systems, focuses more on application and use than on theory; the root of all Expert Systems is theory and it is, therefore, outside the scope of this work's examination. Each of the papers is a technical monograph addressing a subject of very limited scope. The introduction assists the reader put into perspective the intended outcomes from the collection of papers which is the exchange of information on advanced training technologies and products that apply to NATO.

[SIGNAL 1993]

"Modeling Processes Offer Command and Control Aids**."** *SIGNAL*, September 1993.

The author suggests new modeling methods may permit analysts to assess command and control capabilities in the same manner that combat forces are simulated. He argues that functional process improvements which can view all aspects of command and control will result in determining optimum use and benefit. This is a very technical article. The author quickly develops the details of functional process improvements on existing simulations and artificial languages. His recommendations are very specific. This visionary article presents a series of recommendations that will improve command and control capabilities. The application of these new technologies to training command and control, as well as improving command and control in simulations and wargaming, is apparent.

[Simpson et al. 1995]

H. Simpson, W. D. West, and D. Gleisner. *The Use of Simulation in Military Training: Value,* Investment*, and Potential.* DMDC TR 95-007. Defense Manpower Data Center, Monterey, CA, 1995.

This study was conducted in response to a Congressional request to DoD to determine the capabilities and limitations of simulation for training, its impact on training, DoD investments, and whether cost savings were possible though increased use of simulation. It is an expanded version of the DUSD (R) (1995) report. Some key findings were that simulation technology is advancing; the Services accept and use simulation and are making significant investments in them, and simulations have proved to be cost-effective alternatives to traditional methods of training in many areas. Regarding the potential for increased use of simulation, the report drew these conclusions:

Live simulation plays a vital role in preparing our forces for combat. A case can be made for increasing the amount of live simulation in the inter-service and Joint arena. Increased cooperation among the Services in this area has potential to improve the Joint training readiness of the force. Stand-alone single-system simulation is used heavily by the Services and is cost-effective in many applications. The area with the greatest potential payoff for more application is probably in combat aircrew training. With real aircraft, this type of training poses the greatest risk for loss of life and aircraft if mistakes are made. There is not adequate data to make a recommendation regarding the increased use of simulators in lieu of OPTEMPO flying hours per aircraft, steaming days per ship, or ground vehicle miles. In general, the authors believe that the Services should be permitted to make this tradeoff on the basis of their assessment of the impact of simulation on the requirement to maintain readiness. Virtual simulation has the potential to enable Joint and inter-service training in mission areas not being trained in sufficiently now (e.g., close air support). The technology permits coordinated training among the Services while individual Service elements remain at their home stations. This technology is new, though it appears to have great potential. Continued investment should be made in this area to develop, test, and refine the technologies to enable it to reach its full potential. The level of investment in constructive simulation is relatively modest in comparison with the other types of simulation. This does not however decrease its importance, especially in the command staff and Joint training areas. The Joint Staff and the various Unified and Specified Commands place increasing importance on the use of constructive simulations in their training programs. The authors believe that continued investment in constructive simulation based training is essential to the Joint readiness of the Total Force. (p. 26)

[Spindler 1989]

G. B. Spindler. *AC/243 (Panel 7/RSG. 15)D/4 on the Military Value and Cost Effectiveness of Training.* NATO, Brussels, Belgium, 1989.

This document contains a number of case studies concerning the military value and cost effectiveness of training.

[Swinsick 1995]

Scott R. Swinsick, Operations Research Analyst, “Longbow Apache FCR RMAP Model Benefits.” McDonnell Douglas Helicopter Systems, Mesa, Arizona. RFI response 1995.

The benefits associated with the use of manned simulation in Force Development Test and Experimentation (FDT&E), shown in Table 1, are numerous and quantified. FDT&E provided excellent points of comparison since the scenarios and activities conducted in the simulation and the field test were so similar. The FDT&E Phase II was about six times the cost of FDT&E Phase I. It required far more equipment, 24 times the personnel, took longer per trial to complete, and had the inherent risks associated with the operation of aircraft in a realistic environment.

Table 1: Longbow FDT&E

Resources	Phase I Manned Simulation	Phase II Field Test
Cost (O&M Army)	$712,000	4,049,000
Equipment	1 Simulator	4 AH-64D 2 UH-60 14 M1 Tank 10 M3 Fighting Vehicle 2 2S6 20+ ADU 47+ Assorted Vehicle
Personnel (Government)	27	663
Mission Turn-Around Time	2 hours	6 hours
Data Reduction Time	4 hours	80 hours
Number of Trials	32	16
Test Period	4 weeks	6 weeks
Safety	No Risk	Moderate Risk (No Accidents)

FDT&E with the Longbow Integrated Training System has been the most comprehensive Longbow simulation effort to date. From individual training through record trials, many lessons were learned and quantified. The system provided the training necessary to make the crews proficient with the Longbow systems. During FDT&E, the crews were extremely competent and knowledgeable in the use of the Longbow systems and were able to rapidly correct when something went wrong.

A longer collective training period is recommended. The team SOP must be second nature and crews must be working cohesively as a team before record trials begin. The crews conducted only three days of combat missions prior to record trials. At the end of the first week of record trials the crews had reduced threat hits by 33 percent and by the end of week two the threat hits dropped another 30 percent. Moving more combat missions into the collective training phase would improve performance at the start of record trials.

The record trials identified some requirements which must be considered. The ability to rapidly modify scenarios or add new systems to the simulation is a necessity. Diversity in threat array composition and force movement prevents crew complacency with the missions. The threat force must be located to provide the attack helicopter company maximum maneuver space within the simulation database and allow greater experimentation with tactics, techniques, and procedures (TTP). The simulation arena must remain as flexible and changing as the global environment around us.

As experienced in FDT&E, the simulator provides benefits in many ways. New tactics can be exercised against multiple situations with no risk to life or limb. The simulator allows the attack helicopter company to improve proficiency and increase safety before reaching the field by establishing and proving SOP and TTP.

Simulation supports the restructured Army's size, development objectives, and acquisition process. It requires less operational and support costs, no wear on active equipment, fewer test personnel, and no risk to life either human or machine. FDT&E has provided the quantifiable arguments for the application of simulation to training, test, and experimentation.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Firing Impulse Simulator (FIS). The FIS at Aberdeen Test Center (ATC) simulates the recoil/trunnion loads and ballistic shock effects of firing impulses for tanks, and towed and self-propelled howitzers. The FIS delivers approximately 3 million pounds to a system to fully replicate an actual firing without the use of ammunition. The FIS project was a $6.9M investment in simulation technology. Simulated firing with the FIS was performed on the M1A2 trunnion test program in May 1994. Simulated firing with the FIS saves about $23M of cost avoidance for a typical trunnion bearing test. Test crew was reduced from 13 to 4. In addition, nonammunition firings result in significant time savings and significant environmental savings such as noise, toxic fumes, and blast overpressures. A one-year Trunnion Bearing Test is presently half completed to support the M1A2 Abrams and Armored Gun System (AGS). Future tests include the M1A1 Recoil Proofing Test and Composite Vehicle test.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

M830E1 Fuse Testing. In support of the M830E1 test program, Yuma Proving Ground (YPG) developed a computer-based virtual test range simulation for evaluating tank versus helicopter engagements. Flight paths of the helicopter, and trajectories of the prototype round were modeled based on actual flights and previous firings. Simulated helicopter engagements were conducted with an actual manned tank, with projectile (simulated) miss distance recorded for each engagement. Eighty such “virtual” firings were conducted. Then, the simulated engagements were verified by an actual engagement using a live round against a drone aircraft. The actual test cost was $260,000. This results in a cost avoidance of $1.5 M for not having to fire a complete test of live rounds against live targets. Although no further testing is currently scheduled, this technique can be enhanced for future large caliber Air Defense application.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Moving Target Simulator (MTS). The MTS test facility at ATC is designed to assess the ability of the M1A2 tank crew to track and simulate firing on images of simulated maneuvering targets. The MTS allows immersion of complete weapon systems (aircraft or ground based) into a moving visual target environment, to investigate pointing and tracking performance of fire control systems. The simulator projects a laser spot target on the inside of a 100' hemispherical dome. With the test vehicle in the middle of the dome, evasive targets can be simulated for may different ranges. Use of the MTS is estimated to save $1.5 million per year compared to field testing. Approximately 500 simulated engagements were completed in about 3 weeks during a test scenario where it would have required two weeks just to setup and fire a single live round. The effect on acquisition time can be less time spent in testing and retesting. The MTS is now being refurbished for conducting gun positioning, weapon pointing, and gunner tracking testing for the M1A2, AGS, and 120mm mortar.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Millimeter-wave Simulation/Test Acceptance Facility (STAF). The STAF is a joint effort between the Redstone Technical Test Center (RTTC) and the U.S. Army Missile Command. It is a hardware-in-the-loop simulator for testing millimeter wave radar-guided missiles. The STAF provides testing of a fully assembled "live" missile with multiple computer-based test scenarios such as targets, ranges, and temperatures. The STAF allows a random selection of production munitions rounds from a Fly-to-Buy lot and tests these rounds in a real-time non-destructive simulation. RTTC conducted a detailed cost tradeoff for the LONGBOW missile program. Some of the assumptions that entered into the analysis were that destructive firing of four missiles a month would be replaced by STAF method of simulating/testing six missiles per month, and destructive firing of four missiles per year would be used as an additional confidence builder and feedback to the model. If destructive test programs were performed on the LONGBOW, the yearly test cost would be $12.5M. The STAF simulation/test method, however, only costs $1.8 per year, resulting in a cost savings of $10.6M per year. The estimated $10.6M savings is only for the LONGBOW; the Patriot Advanced Capability-3 (PAC-3) and JAVELIN programs are planned to be tested in the STAF with similar expected savings.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Aerial Cable Range (ACR). The ACR at White Sands Missile Range (WSMR) employs a suspended aerial cable system that features highly repeatable test conditions, reusable targets, and fast turnaround of tests. The heart of the ARC is a 3-mile long suspended Kevlar cable that serves as the path for captive vehicles and supports test objects weighing up to 20,000 pounds. It is the longest unsupported cable span in the world. The initial cost of this range was $32.2M. The recently completed tests of the Joint Missile Approach Warning System (MAWS) resulted in a cost avoidance of $13.8M. Use of full-scale drone aircraft would have cost approximately $14.5M. The actual cost of the MAWS test using reusable, captive targets on the ACR was $700,000. The captive targets are not destroyed during testing on the ACR. A “heat source” hangs below the captive target so that the missile would aim at the heat source and not the targets. Other upcoming events include tests for the Apache (AH64) Target Characterization in June 1995 and the Post Burnout testing of Infrared Sensors in July 1995.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Test Item Stimulators (TIS). The TIS at Electronic Proving Ground (EPG) provides non-radiating simulated digital message traffic input to challenge large network, computer based C3 systems. Through the Test Control Center, inputs are time coded according to the mission or exercise scenario, and are variable and repeatable, as required. Through use of these stimulators, and the control model for operating the stimulators and test items, the cost of testing the Enhanced Position Location Reporting System (EPLRS) was reduced by $2 million (30%). Savings were realized through improved test efficiency and reduction of operators required to support the testing. The TIS can be adapted to any communication system. It was also used for Mobile Subscriber Equipment (MSE) test, Joint Tactical Information Distribution System (JTIDS) test, and the Army Tactical Command and Control System (ATCSS) operational test.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Trajectory Sense and Destroy Armor (SADARM) Simulation. Real-time tracking data from range radars are used to model the ballistic simulation for the SADARM projectile trajectory to provide sufficiently accurate pointing data to target area instrumentation. This real-time optimal estimation software enables the downrange auto-trackers to acquire and track the incoming projectile and quickly transition to acquire critical end-game data on SADARM submunitions upon dispense from the projectile. This new tracking capability has avoided $12M in instrumentation cost.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Patriot Simulation Program. The testing of PAC-3 hardware and software is supported by several models and simulators which reduce the requirement for launching targets, firing test missiles and telemetering flight data. The PAC-3, being in the early stages of the development, has not entered Government technical testing. It is anticipated that once testing begins, a considerable amount of savings may be realized through flight mission simulation in lieu of actual firings. Each flight can be simulated numerous times to increase the confidence level of flight test performance without the use of live missiles, targets, instrumentation, and some data reduction expense. Although the Patriot modeling and simulation capabilities belong to either the Patriot Project Office or the Prime Contractor, TECOM will interface with these capabilities during anticipated virtual testing. At about $750,000 per launch of a Patriot missile, modeling and simulation are essential to the PAC-3 test program:

1. The Guidance Test and Simulation Facility is a full hardware-in-the-loop guidance simulator for the Patriot system, providing endgame geometry and miss distance in lethality analyses.

2. The Flight Mission Simulator provides a controlled environment of various simulated target signature and electronic countermeasures in puts to the system surveillance function, as well as simulated missile responses for the guidance function.

3. The Multi-function Simulation models Patriot search, tract, and engagement capabilities under radar loading.

4. The PAC Simulation provides a high fidelity digital simulation of the surveillance function, missile dynamics, and lethality function for pre-flight predictions and post-flight reconstruction of flight tests.

5. The Counter Anti-Radiation Missile is a digital simulation of anti-radiation missile performance against the Patriot system.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Physical Simulation of Bridge Crossing. Traditionally, bridge durability testing is conducted by performing multiple crossings of vehicles. This method requires 12 weeks to conduct 3,000 crossings and costs $325,000. Bridge durability tests are now conducted using a mixture of actual and simulated crossings. ATC conducted the bridge crossing using actual equipment and vehicles that were instrumented to measure physical characteristics, and simulations were conduced using a physical bridge crossing simulator at Fort Belvior. This new simulated test method reduces the time to 9 weeks and costs to $110,000. During future use of the simulator, particularly for unique foreign bridges, this mix of live and simulated testing will be conducted exclusively at Aberdeen.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Vibration Test Facility (VTF). A long-established use of simulation in testing is the simulation of the natural and induced environments to which Army materiel is subjected. One such environment is vibration. Tanks with dummy ammunition are driven around and instrumented to measure the vibration levels. Those profiles are simulated with shaker tables at the VTF. It would take six months of field testing to subject tank ammunition to the transport vibration during its typical life cycle. At $1200 per tank hour, doing this testing “live” would be prohibitive. Instead, 24 hours of transport simulation on a “shaker table” subjects tank ammunition to expected life cycle transport vibration. The VTF is also used to conduct tests where other components (i.e., radios, power units, heater units, environmental conditioning units, and autoloader equipment) are subject to various driving conditions. In both applications, increased simulation capabilities are reducing costly field testing.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Joint Precision Strike Demonstration (JPSD). Redstone Technical Test Center instrumented the Multiple Launch Rocket System (MLRS) Launcher, acquired weapon system performance data, and analyzed the data from the JPSD mission. In addition, WSMR successfully fired live Army Tactical Missiles as part of the distributed JPSD, using interactive live, constructive, and virtual simulation at various sites to develop an Army sensor-to-shooter, precision, deep-strike capability.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Combined Arms Synthetic Experiment (CASE). The CASE is a concept of linking two of our test centers to conduct live, virtual, and constructive simulations. This concept was successfully demonstrated in December 1994. In the CASE demonstration, real weapon systems operating at YPG and WSMR were synthetically fused with a JANUS Warfighting model, using Distributed Interactive Simulation protocols. 3-D displays were generated based on the merged data to provide high resolution visualization of the experiment in near real-time. In addition, the injection of the real entities into the constructive simulation required the transformation of all live entities onto the terrain employed by the model. Pieces and modules of this capability are being developed. This capability should be fully operating in 1998 as part of the VPG. The CASE concept demonstrated the capability to support the Force XXI initiative, Advanced Warfighting Experiments, Advanced Technology Demonstrations, and Joint Service Integration Exercises. A CASE II is planned which will demonstrate additional capabilities and highlight tri-service applications at our Major Range and Test Facility Base (MRTFB).

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

3-D Virtual Test Ranges (VTR). (ongoing). The VTR is generate from DMA Digital Terrain Elevation Data Level II (30 m^2 resolution) merged with weapon system models and human-in-the-loop and hardware-in-the-loop for simulation of weapon system engagements. The VTR includes the Combine Arms Synthetic Experiment which uses Sensor Data Fusion (SDF). The SDF allows Virtual Reality Display of systems where optics fail, e.g., missile cruising at 140,000 ft.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Integrated Radar and Infrared Analysis Modeling (IRIAM) (ongoing). The IRIAM is a tri-service program. It generates 3-D graphics for the representation of test data, real-time visual test reports, and flight test reports. The tri-services are incorporating the Navy infrared modeling software, Air Force aircraft models and weather effects stimuli, and Army virtual display and range control software.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Situational and Reality Display System (SARDS) (ongoing). The SARDS consists of the VTR interfaced to the Global Positioning System Time Space Position Information equipment to provide real-time tracking identify, location, and status of selected aircraft, vehicles, etc.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

C-17 Airdrop (ongoing). The results of live airdrops at YPG are being used to model the airdrop characteristics of the C-17 Globemaster III.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Dynamic Infrared Scene Projector (DIRSP) (ongoing). The DIRSP is a new test technology concept that projects synthetic infrared imagery into the sensor entrance aperture. This system and the imaging infrared sensor are analogous to television and the human eye. The DIRSP, when integrated with existing models and simulation techniques, will bring “field testing” into the laboratory by supplying synthetic infrared field test environments for operational evaluation of imaging infrared sensors, subsystems, and systems.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Covert Remote Electronic Warfare Simulator (CREWS) (ongoing). The CREWS concept is based on replacing the use of high power, broadband jammers to simulate electronics warfare threat systems with a continuous wave tone generator of moderate power. This tone generator is used to radiate a signal of known amplitude in or near the frequency of jamming interest. The CREWS is mounted in either an airborne or ground platform to represent the real threat. For the JTIDS analysis, at least three “good” data points for each jamming condition are required. On an average, a field jamming test requires three flights to get a single valid data point. A live field jamming test for a single jamming condition would cost approximately $52,000. Using the CREWS, the aircraft will be flown one time and the CREWS will record the control tone’s received signal level (RSL); subsequent data points will simply require playing back the recorded RSL information through the CREWS. The CREWS jamming test will cost only $5,000. CREWS modules are being produced in FY95 to instrument the EPLRS, MSE, JTIDS, and Single Channel Ground and Airborne Radio.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Environmental Issues Guide for Heuristic Testing (EIGHT) (ongoing). The EIGHT is a knowledge base of how environments affect materiel systems. The EIGHT is a unique tool that looks at the effects of environments on materiel systems, not impacts of systems on the environment. EIGHT arranges information in a 4-dimensional matrix with about 200,000 cells. Each cell consists of 4 climatic regions (e.g., cold, desert, tropic, and temperate), 50 environmental factors in 4 categories (e.g., natural, induced, constructed, and battlefield), 10 analysis areas (e.g., operability, safety, vulnerability), and 100 mission/commodity areas (e.g., air defense, aviation, command and control). This database provides ground truth for the VPG to define interaction of the test item and the environment, and provides historical test results for different commodity systems and environmental conditions. It, therefore, provides lessons learned from these tests so that mistakes are not repeated and future testing is better focused on relevant parameters whether live or simulated.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

HELLFIRE Simulation (ongoing). The Laser Designator Weapon System Simulation (LDWSS) is accredited for use to extrapolate HELLFIRE weapon system performance based on subsystem/component level testing. The LDWSS model is being upgraded and modified to allow for higher resolution (i.e., discrete component) effects analysis.

[TECOM 1995]
U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories, white paper, August, 1995.

Target Acquisition Model Improvement Program (TAMIP) (ongoing). Models undergoing improvement in the TAMIP to include millimeter-wave, infrared, visible, and acoustic capabilities. The enhanced models provide an objective means for comparing the vulnerability of vehicles a relates to detection on the battlefield. The models are used for quantifying the value added when vehicle signature are reduced, and to drive requirements for signature specification of future vehicles.

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Air Force AMRAAM Test Cost Savings. During the last eight years, more than 130 DT&E missiles have been launched from test aircraft against drone aircraft. In addition, approximately 45 FOT&E missiles have been launched out of a planned total of approximately 65 FOT&E missiles. Only eight live warheads have been used in the approximately 175 launches to date. The end game effectiveness model, SHAZAM, has been successfully used to predict and subsequently to assess the lethality of each missile at end game.

This has resulted in a direct program savings of approximately $250M in drone aircraft costs alone because very few of the drones were damaged by warhead blast or fragments since only eight live warheads were used. In most cases, the $2.5M drones were able to be returned safely and used again and again.

Other, less tangible, benefits were:

> No more F-106 aircraft suitable to be "droned" remained at Davis-Monthan AFB. Drones are now being made from F-4 aircraft and it would be difficult to support a missile flight test program if drones were not returned for reuse.
>
> The environmental impact on the Gulf of Mexico would be significant if hundreds of drone aircraft with leaking fuel tanks were crashed into the water. The use of lethality modeling with SHAZAM precludes this environmental problem.
>
> In actuality, the use of simulation permits the assessment of the entire endgame including the flyby which would be denied if the warhead were detonated and the telemetry ceased to be transmitted. The use of simulation permits collection of these useful data after the warhead would have detonated.

Table 2: AMRAAM Test Costs Savings ROI:

Model Development:	4 people x 2 yr x $125K/yr =	$1.0M	
Analysis Support:	4 people x 8 yr x $125K/yr =	$4.0M	
Lethality Tests:	Range time and people =	$1.5M	
Total Investment:		$6.5M	
Direct Savings:		$250.0M	
ROI		$250M/$6.5M =	38

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

GBU-28 Precision Guided Weapon Test Savings. The GBU-28 was developed at Eglin AFB in less than six weeks in response to an urgent need during Desert Storm. The short time did not permit any of the normal testing which usually accompanies any weapon development program.. this, the program management relied almost exclusively on lethality and vulnerability modeling to design and predict the performance of the new weapon system

The depth of penetration into the subterranean structures was calculated using analytically derived penetration equations. One drop test of an inert GBU-28 was conducted on one type of soil to check the model; however, the primary purpose of the drop test was to verify the structural integrity of the steel case. The performance of the GBU-28, the depth of penetration, the lethality of the warhead in a new case, and the vulnerability of the targets were predicted successfully by lethality and vulnerability models. Live GBU-28 weapons were dropped during the air war without any prior drops of a live GBU-28 based on the confidence in current lethality and vulnerability models.

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Mk Series Bomb Fragment Data. The Mk-84 general purpose bomb was retrofitted by the Air Force to have the option for either tail or nose fuzing or both. Arena tests were conduced at a cost of more than $400K to determine the difference in fragment spray patters resulting from nose and tail fuzing. Based on the above arena tests, lethality modeling techniques were developed to model the lethal fragment spray pattern. This, in turn, permitted both the Mk-82 and the Mk-83 general purpose bomb fragment spray patterns to be characterized without the expenditure of nearly $900K for additional arena tests.

Table 3: Mk Series Bomb Fragment ROI:

Model Development:	Used JMEMS (sunk cost) =	$0.0K	
Analysis Support:	2 people x .33 yr x $125K/yr =	$82.5K	
Total Investment:		$82.5K	
Direct Savings:		$900.0K	
ROI		$900K/$82.5K =	11

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Determination of BLU-109 Performance Envelopes. When the BLU-109 was under development by the Air Force, it was necessary to conduct numerous drop tests of the weapon from an aircraft to determine the limits of impact angle, impact speed and angle of attack which would permit successful penetration (without ricochet or partial penetration) of concrete surfaces such as runways. More than 80 tests at approximately $50K per drop were planned to obtain the required data.

Program analysts recommended the use of an analytical technique to reduce the number of drops from 80 to only 15 while still providing the required data to assess the lethality of the BLU-109 warhead throughout the performance envelope. This use of lethality modeling resulted in a one time cost savings of more than $3M on this one weapon system.

Table 4: BLU-109 Performance Envelope

Model Development:	Integral with analysis =	$0.0K	
Analysis Support:	2 people x .33 yr x $125K/yr =	$82.5K	
Total Investment:		$82.5K	
Direct Savings:		$3.0M	
ROI		$3.0M/$82.5K =	36

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Air-to-Air Missile Engagement Analysis. Beginning in 1980 the Air Force conducted an air-to-air missile engagement analysis called ACEVAL/AIMVAL which involved multiple aircraft in mock aerial duels. This effort cost more than $50M and required more than three years to complete.

A few years later, the AMRAAM Program required similar, but additional, data on the effectiveness of AMRAAM when used in conjunction with short-range missiles in aerial combat situations. Program analysts successfully convinced the program management that the required data could be obtained without the costly flight tests by using lethality modeling combined with aerial engagement modeling.

As a result, the AMRAAM Operational Utility Effectiveness analysis was conducted for $20M in two years, a savings of $30M and one year. One added advantage was that three times as many engagements were analyzed than would have been done in mock combat.

Table 5: Air-to-Air Missile Engagement Analysis ROI:

Model Development: Analysis Support:	Single cost includes both model development and analysis over a two year period	$20.0M	
Total Investment:		$20.0M	
Direct Savings:	Test costs not incurred = 200 people x 1 yr x $125K/yr =	$50.0M $25.0M	
Total Direct Savings:		$75.0M	
ROI		$75.0M/$20.0M =	4

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Wide Area Anti-armor Munition (WAAM). The Air Force conducted developmental work on this system in the early 1980s but did not continue into full scale development or production because lethality analyses showed that the system could not obtain the required kills per pass required to make the system cost effective. The cancellation of this program was based on lethality analysis and resulted in estimated cost savings of $30M for the planned full-scale development effort.

Table 6: Wide Area Anti-armor Munition ROI.

Model Development:	Integral with analysis =	$0.00M	
Analysis Support:	6 people x 1 yr x $125K/yr =	$0.75M	
Total Investment:		$0.75M	
Direct Savings:		$30.00M	
ROI		$30M/$0.75M =	40

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Hypervelocity Missile. The Hypervelocity Missile program was terminated in the early stages of full scale development based on an analysis using lethality models which indicated that the payoff would not be as great as expected during the initial planning effort. The cancellation of this effort was based solely on a lethality analysis and resulted in an estimated cost savings of $10M for the remaining full scale development effort.

Table 7: Hypervelocity Missile ROI.

Model Development: Analysis Support:	Integral with analysis = 4 people x 1 yr x $125K/yr =	$0.00M $0.50M	
Total Investment: Direct Savings: ROI		$0.50M $10.00M $10M/$0.50M =	 45

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Intelligence Shelter Attack Submunition (ISAS). The German government proposed a joint development effort with the US to develop this weapon system in 1987 for a total development cost of approximately $80M. After setting up a joint program office at Eglin AFB and signing the appropriate agreements, a detailed cost-effectiveness analysis was conducted using lethality models to determine the payoff of the ISAS to the Air Force if it were developed. The results of the analysis clearly showed that the system would not perform under all conditions and would not be advantageous to the Air Force. Thus the program was canceled solely upon the results of a lethality analysis with a resultant savings of $40M, the Air Force share for the proposed development effort.

Table 8: Intelligence Shelter Attack Submunition ROI.

Model Development: Analysis Support:	Integral with analysis = 4 people x 1 yr x $125K/yr =	$0.00M $0.50M	
Total Investment: Direct Savings: ROI		$0.50M $10.00M $10M/$0.50M =	 45

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Kinetic Energy Penetrator (KEP). The Air Force developed a working version of a new runway penetrator called the Kinetic Energy Penetrator (KEP) which was ready for production in 1980. At the request of management, a tiger team was convened to determine the suitability of the system for production. After a review of the program and the completion of a detailed effectiveness analysis using lethality models of the system, the program was canceled. The technology was set on the shelf and the Air Force saved a minimum of $50M in production costs which were never incurred.

Table 9: Kinetic Energy Penetrator (KEP).

Model Development:	8 people x 3 mo x $125K/yr =	$0.25M	
Analysis Support:	16 people x 3 mo x $125K/yr =	$0.50M	
Range Tests:	Range time and people =	$0.30M	
Total Investment:		$0.75	
Direct Savings:		$40.00M	
ROI		$40M/$0.75M =	53

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

JP-233 Runway Attack Munition. The JP-233 was a joint development effort conducted with the United Kingdom during the late 1970s. After spending several millions in the development costs with the UK, the program was finally ready for production in the early 1980s. Before commitment to production, the US Air Force commissioned a study to determine the cost effectiveness of the JP-233 for Air Force use. The resulting analysis using both lethality and vulnerability models clearly showed that the system was not cost effective for Air Force use. The use of L/V modeling in this case resulted in the US withdrawal from the program and saved the Air Force more than $50M in production costs for a weapon which was not cost effective.

Table 10: JP-233 Runway Attack Munition.

Model Development:	4 people x 3 mo x $125K/yr =	$0.15M	
Analysis Support:	20 people x 3 mo x $125K/yr =	$0.65M	
Range Tests:	Range time and people =	$0.30M	
Total Investment:		$1.10M	
Direct Savings:		$54.00M	

ROI		$54M/$1.10M =	49

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Boosted Kinetic Energy Penetrator (BKEP). After withdrawal from the JP-233 program the US Air Force spent several years and millions of dollars developing their own runway defeat munition, called BKEP. After completion of full scale development in 1987, continuing analysis of the BKEP's effectiveness by Air Force analysts using runway vulnerability models resulted in the determination that the BKEP would not be able to defeat some of the new runway designs being installed at the Warsaw Pact airbases. Based primarily on the results of this vulnerability analysis, the BKEP program was canceled with an estimated $130M savings in production costs alone.

Table 11: Boosted Kinetic Energy Penetrator ROI.

Model Development: Analysis Support: Range Tests:	4 people x 6 mo x $125K/yr = 12 people x 1 yr x $125K/yr = Range time and people =	$0.25M $1.50M $1.00M	
Total Investment: Direct Savings: ROI		$2.75M $130.00M $130M/$2.75M =	47

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

JAVELIN Antitank Guided Missile. In the mid-1980s, the Army initiated development of a new man-portable antitank guided missile to counter recent changes in the armor threat. Soviet tanks had become more heavily armored, and it was clear that a new warhead technology was needed, and that an unconventional flight trajectory was required to deliver the warhead against the "softer" portions of a target. Without these advanced technologies, it was not possible to achieve the desired lethality within acceptable weight constraints.

By use of flight simulation models and terminal lethality models, various delivery strategies and warhead technologies were evaluated . In this way, the best design approach was identified without destructive testing. Further, the required warhead size was determined by parametrically varying the size and computing kill probabilities.

By contrast, when the Army started development of its first antitank guided missile, the Shillelagh, it was not known what warhead size was needed to defeat the threat tanks of the day, and no models were available to address the question analytically. It was necessary to conduct a rather large experiment in which a scaled family of warheads were fired against tanks to observe the lethality as a function of size. One hundred twenty warheads were fired and tanks were destroyed. If it were necessary to conduct such an experiment today, the cost would be in the neighborhood of $10 million plus the cost of the target tanks. Thus, it is conservatively estimated that analytical simulation for the man-portable anti-tank guided missile saved at least $10M.

Table 12: JAVELIN Antitank Guided Missile ROI.

Model Development: Analysis Support:	1 person x 6 mo x $125K/yr 6 people x 9 mo x $125K/yr =	$0.06M $0.56M	
Total Investment: Direct Savings: Total Direct Savings: ROI	 Test costs = Tanks saved = 8 x $0.50M =	$0.62M $10.00M $4.00M $14.00M $14M/$0.62M =	 23

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

M2 Bradley Fighting Vehicle System. When the Army began development of the M2 Bradley Fighting Vehicle System, it faced a unique problem. The Army had never had a vehicle of this type, i.e., a vehicle which both transports an Infantry squad and possesses significant firepower. While the intended tactical role of the vehicle was defined, there was no basis in experience for selecting the vehicle characteristics that would best serve the planned tactical role. The only experimental approach to the problem was to design and construct several prototypes and subject them to field testing at a cost of tens of millions of dollars.

Using analysis techniques, it was possible to address the issues analytically and save nearly all of this cost. Preliminary design concepts were sought from industry and from government with different design features. Each of these designs was evaluated analytically in terms of vulnerability, mobility, firepower characteristics, estimated cost, and logistic burden. With the results of these evaluation as inputs, the combat effectiveness of each design was estimated by use of a combat simulation model. The results of these evaluations allowed the Army to select the best vehicle for engineering development on a stronger basis than had been possible on any previous occasion and at an estimated savings of tens of millions of dollars.

Table 13: M2 Bradley Fighting Vehicle ROI.

Model Development:	2 people x 6 mo x $125K/yr	$0.13M	
Analysis Support:	6 people x 1 yr x $125K/yr =	$0.75M	
Total Investment:		$0.88M	
Direct Savings:		$30.00M	
ROI		$30M/$0.88M =	34

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Abrams M1A2 Tank Vulnerability Testing. The requirement for ballistic vulnerability testing on fully operational Abrams tanks was reduced by conducting vulnerability computer modeling to predict damage from penetrating threats before "Controlled Damage" tests were conducted. In effect, the computer predictions permitted the damaged components to be identified and disabled in the Controlled Damage tests and the tests permitted the degradation of the system in combat to be determined without damage to the total Abrams vehicle. Costs for repair of ballistic damage to one Abrams can run as high as $1.5 million per shot if damage were catastrophic. For a series of 20 Controlled Damage tests, the total cost was $80K, compared with a potential loss of $30M for 20 tests on the full-scale Abrams. The 20 Controlled Damage tests, based on computer simulations to predict damage, cost only $80K which was a savings of $29M.

Table 14: Abrams M1A2 Vulnerability ROI.

Model Development:		$1.00M	
Analysis Support:	6 people x 1 yr x $125K/yr =	$0.75M	
Controlled damage tests:	20 tests x $4K/test =	$0.008M	
Total Investment:		$1.83M	
Direct Savings:		$30.00M	
ROI		$30M/$1.83M =	16

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Block 3, M1A2 Abrams Tank. During the development of the Block 3, M1A2 Abrams tank, an analysis of the radical front-engine tank design was conducted to assess the vulnerability of the design. The results of the analysis clearly showed the new design to be very vulnerable to certain threats which Desert Storm data proved to be correct. As a result, a very costly development program was terminated with a savings conservatively estimated to be more than $100M for development.

Table 15: Block 3, M1A2 Abrams Tank Design ROI.

Model Development:	3 people x 1 yr x $125K/yr	$0.38M	
Analysis Support:	7 people x 1 yr x $125K/yr =	$0.88M	
Field Tests:	Range time and people =	$0.05M	
Total Investment:		$1.76M	
Direct Savings:		$100.00M	
ROI		$100M/$1.76M =	57

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Standard Missile (SM-2 BLK IIIA) DT&E/OT&E Flight Tests. The Navy was directed to reduce costs by $47M on the planned flight tests. This required the elimination of 13 missile flight tests out of the planned 30 tests. As a result, the Navy was required to upgrade the existing COVART lethality model and the end-game effectiveness model called WHDEVAL to evaluate the performance of the SM-2 at regions of the performance envelope which could not be tested. The missile system was subsequently accepted based on the reduced number of flight tests and an increased amount of simulation and analysis using the above L/V models.

Table 16: Standard Missile (SM-2 BLK IIIA) ROI

Model Development:			
COVART:	2 people x 2 yr x $125K/yr =	$0.50M	
WHDEVAL:	3 people x 2 yr x $125K/yr =	$0.75M	
Analysis Support:	3 people x 2 yr x $125K/yr =	$0.75M	
Lethality Tests:	2 people x 1 yr x $125K/yr =	$0.25M	
Total Investment:		$2.25M	
Direct Savings:		$47.00M	

ROI		$47M/$2.25M =	21

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

PHALANX Close in Weapon System (CIWS) Block 0, DSARC III Decision. After spending more than $125M on development of the Phalanx Naval gun system, Congress was ready to cancel the program based on the first test results in 1975. Since a new gun system design would cost at least $125M at that time, Congress was persuaded to delay program cancellation until the necessary analytical models were developed to evaluate the Phalanx performance at all conditions without extensive hardware testing. Within three years, three models were developed and validated based on extensive laboratory lethality tests. The resulting analyses were of sufficient quality to convince Congress to reinstate the original Phalanx program based primarily on the results of analytical modeling and simulation at a minimum savings of $125M.

Table 17: PHALANX CIWS Block 0 ROI.

Model Development: Multiple Plate Pen Model: Probability of Hit Model: Gun Effectiveness Model:	 3 people x 2 yr x $125K/yr = 2 people x 2 yr x $125K/yr = 3 people x 2 yr x $125K/yr =	 $0.75M $0.50M $0.75M	
Analysis Support:	3 people x 3 yr x $125K/yr =	$1.12M	
Lethality Tests:	people and test assets =	$5.00M	
Total Investment:		$8.12M	
Direct Savings:		$125.00M	
ROI		$125M/$8.12M =	15

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

PHALANX CIWS Upgrade Tradeoff Study. Within 10 years after IOC of the Phalanx, the advent of new threats required either development of a new CIWS or improvements in the original Phalanx capability. By using upgraded version of the existing lethality models developed for the original Phalanx CIOWS, and in-depth analysis of the various options proved analytically that upgrades to the original Phalanx design would provide the performance to defeat the improved threat without extensive field testing. The impact of this analysis was to eliminate more than $200M in design and production costs of a new system.

Table 18: PHALANX CIWS Upgrade Tradeoff Study ROI.

Model Development: Multiple Plate Pen Model: Probability of Hit Model: Gun Effectiveness Model:	 3 people x 1 yr x $125K/yr = 2 people x 1 yr x $125K/yr = 2 people x 1 yr x $125K/yr =	 $0.38M $0.25M $0.25M	
Analysis Support:	4 people x 2 yr x $125K/yr =	$0.75M	
Additional Lethality Tests:	people and test assets =	$5.00M	
Total Investment:		$6.63M	
Direct Savings:		$200.00M	
ROI		$200M/$6.63M =	30

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

AIM-7P Sea Sparrow Ship Launches. The Navy developed a version of the AIM-7 for ship launch against specific threats. Initially, 10 launches were conducted successfully out of a planned 50 launches. The cost of each launch was $150K for the missile and $250K for the actual test; or a total of $400K each. By using SCAN, the Navy's end-game effectiveness model, to predict the lethality of the missile for the 40 remaining flight tests the Navy was able to eliminate $16M in flight test costs. In addition, the use of lethality analysis instead of flight tests reduced the total time required to put the AIM-7P into production.

Table 19: AIM-7P Sea Sparrow ROI.

Model Development:	2 people x 6 mo x $125K/yr =	$0.12M	
Analysis Support:	3 people x 1 yr x $125K/yr =	$0.38M	
Laboratory Tests:	people and hardware =	$0.20M	
Total Investment:		$0.70M	
Direct Savings:	40 tests at $400K each =	$16.00M	
ROI		$16M/$0.7M =	23

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Phoenix Missile 6 vs. 6 Tests. The Navy conducted dozens of live firings of the Phoenix air-air missile during development and operational testing of the system. With a production missile cost of $2M each a single live firing against one drone costs in excess of $2.5M. Multiple firings of six Phoenix missiles against six target drones simultaneously cost in excess of $14M. In recent years SCAN, the Navy's end-game effectiveness model, has been used to negate the need for additional 6 vs. 6 live firing tests every time a new threat is encountered or the Phoenix missile has a new upgrade. Over a many year period, lethality modeling has been used successfully for 6 vs. 6 analysis five times with a savings in test costs on the order of $70M with a minimum of analysis costs.

Table 20: Phoenix Missile 6 vs. 6 Tests ROI.

Model Development:	2 people x 2 yr x $125K/yr	$0.50M	
Analysis Support:	5 tests 3 people x 4 mo x $125K/yr =	$0.63M	
Laboratory Tests:		$1.10M	
Total Investment:		$2.23M	
Direct Savings:		$70.00M	

ROI		$70M/$2.23M =	31

[TILV 1995]
DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, May 4, 1995.

Electronic Countermeasures (ECM) Against Navy AMRAAM. The Navy has conducted hundreds of flight tests of ECM against AMRAAM at $700,000 per sortie with approximately 10 intercepts per sortie. This costly procedure has been largely replaced by using a modified version of SCAN, the Navy's end-game effectiveness model, to evaluate the performance of AMRAAM when subjected to numerous types of ECM waveforms. Although some flight tests are still conducted, thousands of engagement simulations using the SCAN model are now used routinely to replace flight test. The savings are in the millions of dollars per year and are expected to continue yearly as new ECM techniques are evaluated.

Table 21: ECM Against Navy AMRAAM ROI.

Model Upgrade: Analysis Support: ECM Support from Lab:	1 person x 1 yr x $125K/yr 2 people x 1 yr x $125K/yr =	$0.13M $0.25M $0.20M	
Total Investment: Direct Savings (1 yr): ROI	 150 missions x $70,000 ea =	$0.58M $10.50M $10.5M/$0.58M =	 18

[Tillson et al. 1992*]*
J. C. Tillson, M. L. Roberson, and S. A. Horowitz. *Alternative Approaches to Organizing, Training and Assessing Army and Marine Corps* Units *Part II, The Reserve Component.*
Institute for Defense Analyses, Alexandria, VA, November 1992.

There are two goals for this two-part study. Part I seeks to develop alternative approaches to organizing the Active Component of the Army and the Marine Corps to allow both services to maintain force structure and training readiness despite anticipated reductions in resources and operating tempo. In Part II, the goal is to develop and analyze alternative ways of organizing and training Reserve combat forces that will allow them to better serve the nation's diverse needs. The study also addresses changes in the world that make this study important, such as, the shape of the future battlefields and the implications these battlefields will have on future training and organizing of US Forces. Chapter 7, "New Approaches to Using Simulation for Training" and Chapter 8, "New Approaches to Using Simulators for Training" are the most interesting to the M&S community. These chapters describe a new approach to using virtual and constructive simulation for training the Army National Guard (ARNG) and US Marine Corps Reserve (USMCR) combat maneuver units. It adapts current simulations training for the Active Component to geographically removed Reserve and National Guard units by applying new technologies available for distance learning. This linkage for distance learning allows training as a cohesive unit. Previously, geographically separated units had virtually no options available to them if they desired to leverage the Active Component simulation exercises. Now, ARNG and USMCR units are able to experience the same staff training exercises available to the Active Component.

[Watson & Cooper 1988]
B. A. Watson, & R.B. Cooper. *Relating Tank Gunnery Performance to Operational Effectiveness* (Study Summary). TRADOC Systems Analysis Activity, White Sands Missile Range, NM, 1988.

[Wilhoite 1993]
B. K. Wilhoite. "Bytes Vs. Bullets: Crew-Served Weapons Simulation Based Training." *Proceedings of the 15th. Interservice/Industry Training Systems and Education Conference.* Orlando, FL, December 1993 475-480).

Wilhoite describes the ongoing evaluation of the Indoor Simulated Marksmanship Trainer (ISMT) an advanced small arms trainer capable of providing simulation training for individuals and teams for every weapon in a USMC infantry battalion. Students who were able to use PGTS in addition to traditional instruction generally performed better than those receiving traditional training alone. Significant cost savings are possible as simulation is used in lieu of live fire during training.